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ERRATA.

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On Page	*Read*	*For*
320	Fig. 2.—Ratio of weight of leaves to stalk at weekly intervals.	Fig. 1.—Graph showing total leaf area and dry matter accumulation at weekly intervals.
326	Fig. 1.—Graph showing total leaf area and dry matter accumulation at weekly intervals.	Fig. 2.—Ratio of weight of leaves to stalk at weekly intervals.

STUDIES ON THE SALINE AND ALKALINE SOILS OF DELHI STATE VILLAGES

By S. P. Raychaudhuri and N. S. Sinha, Indian Agricultural Research Institute, New Delhi

[Received for publication on November 3, 1954
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THIS Article is a part of the detailed studies on the saline and alkaline soils of Delhi State, [Raychaudhuri and Sankaran, 1952] which is under semi-arid climate and possesses a large tract of saline and alkaline soils.

Earlier workers had examined soil profiles from different parts of the Delhi State. Raychaudhuri and Sankaran [1952] took three soil profiles on Excort's Farm near Azadpur village, while Raychaudhuri and Tripathi [1953] studied two profiles from village Madanpur. Both these villages are situated in the *khadar* or new alluvium deposits of river Jumna. The profiles studied by Tamhane *et al.* [1953] were taken from Botany Fields of Indian Agricultural Research Institute and Nimgade studied profiles from Gheora and Qamaruddin Nagar villages. Gheora is situtated in the *bangar* area of old alluvium with drier and more sandy uplands ; while Qumaruddin Nagar is in the *dabar* area of old low lying flooded alluvium.

The materials for this study consist of one profile in the village Nangloi Jat and 13 surface soils in the neighbouring areas. The profile selected represented the average condition of salinity found in the tract. The profile did not exhibit any marked horizon differentiation. The characteristics of the profile are given below :

Description of profile :

Location : Nangloi Jat, Delhi State

Date of examination : 22-10-1951

Topography : Low lying area ; rainfall 25 inches

Vegetation : Doob grass (*Cyanodon dactylon*) was most commonly seen

Past and present use : Pea was the previous crop which gave low yields, sugarcane was standing with uneven growth, while patches with no vegetation were seen

DESCRIPTION

Depth (inches)	
0·3·5	Light grey loam, structure columnar, angular; roots profusely spread throughout; compact; no concretions; slight effervescence with dilute HCl
3·5-10	Dark grey clayey loam; structure columnar; angular; roots in quite good number; compact; no effervescence
10-22	Yellowish grey loam; structure cloddy to angular; few roots; brown and yellow spots are seen
22-39	Yellowish grey loam; very wet soil; structure cloddy to angular; brown and yellow mottlings quite marked showing precipitation of sesquioxides in its most preliminary stage. Much darker than the above layer

The surface samples were collected from fields containing black and white alkali spots which were surrounded by areas where the crops grew scantily. The methods of analysis were the same as described in earlier parts of the series. The figures of analysis have been given on oven-dry basis.

RESULTS AND DISCUSSION

Mechanical analysis

The data on the physical constants and mechanical analysis of profile samples are given in Table I.

There was an increase in the clay content with depth in the profile up to third layer with an accumulation of clay at a depth of 10 to 22 inches. The layers of clay accumulation was characterised by presence of yellow mottlings of sesquioxides and colour darker than other horizons. Coarse sand was low in all layers except the top one. The greater colloidal matter content of the clay in the lower layers indicates mechanical eluviation but there was no major textural variation since all of them fall under the group of loam [Marshall, 1947].

The pore space decreased from 45·45 per cent to 28·74 per cent (Table I).

This indicated that the soils were not well aerated and also showed bad drainage due to which water-logging took place for about two months. Moisture equivalent figures as well as sticky point showed a marked increase with depth and was positively correlated with exchangeable sodium percentages.

The figures of dispersion coefficients and dispersion factor are presented in Table IV and total water soluble salts, exchangeable sodium, pH and degree of alkalisation are reproduced in the same Table to facilitate the study of interrelationships. It is observed that the increase in degree of alkalisation with the increase of dispersion coefficient is in accordance with the observations made by Puri [1930] and there was quite a good correlation between the exchangeable sodium and dispersion coefficient.

TABLE I

Mechanical analysis, physical constants and $CaCO_3$ in the profile

Lab. No.	Depth in inches	Clay per cent	Silt per cent	Fine fractions	Fine sand per cent	Coarse sand per cent	$CaCO_3$ per cent	Exchangeable sodium per cent	Sticky point	Moisture equivalent	Pore space per 100 c.c.	Volume expansion per 100 c.c.
1	2	3	4	5	6	7	8	9	10	11	12	13
592/51	0—3·5	14·48	16·35	30·83	65·98	0·89	1·04	24·67	18·61	15·24	45·45	3·87
591/51	3·5—10	19·76	17·36	37·12	60·4	0·29	0·67	28·51	20·84	21·76	40·98	3·27
594/51	10—22	22·09	15·83	37·92	62·27	0·13	0·37	34·31	22·62	22·80	28·74	3·67
595/51	22—38	20·90	16·34	37·24	59·93	0·26	0·74	37·25	24·72	27·50	31·46	3·98

TABLE II

Dispersion factor and dispersion coefficient of the soils of the profile

Lab. No.	Depth in inches	Dispersion factor	Dispersion coeff.	Total soluble solid per cent	Ex. Na. m.e./100 gm.	D.A.	pH	Total B.E.C.
592/51	0—3·5	2·2	15·19	0·206	24·67	28·36	7·59	9·2
593/51	3·5—10	10·05	50·86	0·296	28·51	36·45	8·28	8·1
594/51	10—22	16·75	75·82	0·384	34·31	48·28	8·41	5·8
595/51	22—38	19·35	92·58	0·479	37·25	50·47	8·41	6·2

In the 4th layer the exchangeable Na per cent was maximum (37·25 per cent). The pH showed a direct correlation with the percentage of sodium. The degree of alkalisation was the ratio of monovalent bases present in the soil to the base-exchange capacity, and had been expressed as percentage. The degree of alkalisation increased with depth.

The chemical constituents of profile samples are given in Table III.

TABLE III

Chemical constituents

Depth (in inches)	0—3·5	3·5—10	10—22	22—38
Loss on ignition	3·84	3·64	3·21	3·45
Silica	75·94	71·80	70·97	72·29
Sesquioxides (R_2O_3)	14·63	19·94	21·18	21·42
CaO	1·65	1·03	1·02	0·82
MgO	0·77	0·75	0·95	0·39
K_2O	1·32	1·25	1·14	1·61
P_2O_5	0·18	0·09	0·08	0·05
Organic carbon	0·65	0·53	0·29	0·15
Total nitrogen	0·07	0·06	0·04	0·03
C/N ratio	9·3	8·8	7·2	5·0

The content of silica decreased in second and third layers and increased slightly again in the fourth layer, eluviation of sesquioxides was quite prominent.

It was observed that C/N ratio of the bottom two layers was fairly low. The values of both organic carbon and total nitrogen showed a decrease with depth in all layers and, in general, were low. The soils of semi-arid regions generally contained lower amounts of these nutrients and this tendency was amply reflected in the soils of the profile.

Chemical composition of clays

Data on a few chemical constituents of clays separated from soils are presented in Table IV.

TABLE IV

Composition of clay fractions from soils of the profile

(per cent on oven-dry basis)

Depth in inches	0—3·5	3·5—10	10—22
SiO_2	51·63	49·73	48·65
Al_2O_3	27·55	27·99	27·66
Fe_2O_3	12·32	13·87	15·20
CaO	0·42	0·35	0·28
MgO	1·39	1·52	1·91
K_2O	4·95	5·07	5·93
SiO_2/R_2O_3	2·89	2·31	2·23
SiO_2/Al_2O_3	3·18	3·03	3·00

The data in Table IV show that silica decreased along with depth, while alumina remained more or less constant and ferric oxide increased from 12·32 to 15·20 per cent. The eluviation of iron was quite apparent while examining the profile, and this was confirmed by laboratory data. There was very slight variation in the SiO_2/R_2O_3 ratios in different layers.

The present materials of the *khadar* and *bangar* alluvium as determined by mineralogical analysis [Sen, 1952] indicate that they are quite distinct from each other. The Delhi quartzites, without in any way being related to either of them, have partitioned Delhi district into two distinct areas -the eastern side occupied by the young riverine sediments (*khadar*) and the western side occupied by comparatively older aeolian sediments (*bangar*).

Water soluble salts : Data are presented in Table V.

TABLE V

Total water soluble salts

Depth in inches	NO_3 per cent	CO_3 per cent	HCO_3 per cent	Cl per cent	SO_4 per cent	Ca per cent	Mg per cent	K per cent	Na per cent	Total solids at 105°C observed per cent
1	2	3	4	5	6	7	8	9	10	11
0—3·5	0·028		0·071	0·005	0·033	0·002	0·0006	0·0018	0·052	0·2061
3·5—10	0·019	0·001	0·098	0·008	0·083	0·009	0·002	0·004	0·073	0·296
10—22		0·0012	0·110	0·022	0·128	0·012	0·006	0·007	0·088	0·384
22—38		0·002	0·085	0·025	0·229	0·012	0·018	0·019	0·098	0·479

There is a tendency for the water soluble salts to increase with depth. Carbonate was not present in surface layer whereas it increased with depth. Sulphate predominated in the 3rd and 4th layers where the highest accumulation of soluble salts occurred. Chlorides were also present in higher amount in the 3rd and 4th layers but on the whole they occurred in much smaller amounts than the sulphates. With the exception of sodium, all the bases were present in negligible quantities. The predominance of sodium salts over others especially in 3rd and 4th layers confirmed the view regarding the origin of salts from ground water.

Surface soils

The descriptions of the surface samples are as follows :

(i) *Sample from the field of Shri Qabool Singh (Village Nangloi Jat)*. Low lying field ; water table at about 4½ ft. from the surface. Heavy loam in texture ; dark grey in colour. White encrustations on the surface. The field was lying fallow and the vegetation confined mostly to *doob* grass (*Cyanodon dactylon*).

(ii) *Sample from the field of Shri Ram Chander—(Village Nangloi Jat)*. The surface had at some places black colour ; loamy soil with cloddy or columnar structure ; standing crop was sugarcane.

(iii) *Sample from the field of Shri Ram Chander (Village Nangloi Jat)*. Loamy soil ; no irrigation ; manured ; water logging took place.

(iv) *Sample from the field of Shri Hem Chander—(Village Tilangpur)*. Sandy loam ; light brown colour ; in an adjacent field *kankar* was seen at a depth of about 10 ft.

(v) *Sample from the field of Shri Chandi Ram—(Village Tilangpur)*. Used as grazing ground ; very hard soil ; loam, dark grey colour with cloddy structure.

(vi) *Sample from the field of Shri Ram Gopal (Village Rhenola)*. Fallow field ; serious water logging was reported ; white encrustations on the surface ; sandy loam, compact and hard.

(vii) *Sample from the field of Shri Khem Chand—(Village Rhenola)*. Sandy loam texture ; light grey colour ; *taramira* was sown in the field.

(viii) *Sample from the field of Shri Sarupa—(Village Narula)*. Field lying fallow ; sandy texture ; light grey colour ; used as grazing ground.

(ix) *Sample from the field of Shri Hem Raj—(Village Narula)*. Sandy texture and light grey colour ; standing crop barley and wheat.

(x) *Sample from the field of Shri Nathu Singh—(Village Shafipur)*. Hard soil, irrigated 5 days back ; standing crop—wheat ; sandy loam texture ; grey colour ; no effervescence with dilute HCl.

Three surface samples were taken from the Botany Farm (I. A. R. I.). The samples (No. 17/52 and 19/52) were collected from Plot Nos. 16 and 52, where there were crops of gram and wheat respectively. Plot No. 52 was irrigated five

TABLE

Mechanical analysis of surface soils

Sl. No.	Lab. No.	Clay per cent	Silt per cent	Fine fract. per cent	Fine Sand per cent	Coarse sand per cent	$CaCO_3$ per cent	Textural class
1	2	3	4	5	6	7	8	9
				Nangloi Jat				
1	596/51	21·25	7·42	28·67	68·48	1·41	1·54	Clayey loam
2	597/51	20·98	8·72	29·70	67·08	1·34	0·88	Clayey loam
3	598/51	15·83	13·94	29·77	66·08	1·01	2·01	Loam
				Tilangpur				
4	9/52	11·52	4·53	16·05	80·89	0·84	0·48	Sandy loam
5	10/52	11·82	12·75	24·57	73·72	0·76	0·64	Loam
				Rhenola				
6	12/52	9·39	4·71	14·10	83·75	1·14	0·30	Loamy sand
7	426/52	[illegible]	7·65	16·63	81·46	0·98	0·72	Sandy loam
				Narula				
8	424/52	10·89	9·72	20·61	77·24	0·87	0·14	Sandy loam
9	425/52	12·27	10·46	22·73	72·98	1·04	0·12	Loamy sand
				Shafipur				
10	11/52	7·65	7·12	14·77	83·75	1·14	0·30	Loamy sand
				Botany Farm (I. A. R. I.)				
11	17/52	15·00	6·71	21·71	74·72	2·65	0.51	Sandy loam
12	18/52	10·88	10·64	21·52	75·82	1·31	2·01	do.
13	19/52	12·76	5·52	17·78	79·32	1·91	0·62	do.

VI.

from different Delhi villages.

Water holding capacity per cent	Pore space per 100 cc.	Volume expansion per 100 cc.	Ex. Na per cent	Sticky point per cent	Moisture equivalent	Total B. E. Cap.	D. A.	*p*H
10	11	12	13	14	15	16	17	18
				Nangloi Jat				
37·61	49·33	4·40	30·28	22·62	22·33	10·50	40·50	8·06
35·93	42·38	5·27	33·57	21·87	24·20	9·5	41·05	8·41
32·72	40·91	8·78	12·24	19·72	22·72	9·5	18·50	8·27
				Tilangpur				
31·69	42·45	8·91	12·38	18·61	10·80	12·95	27·20	7·65
31·19	39·82	10·31	24·91	19·09	14·89	6·52	38·7	8·2
				Rhenola				
30·38	34·53	13·20	33·02	16·57	17·60	12·06	46·80	8·35
30·18	38·02	3·75	26·73	18·76	14·26	11·82	39·68	8·4
				Narula				
31·27	42·36	4·48	..	17·58	16·77			
33·31	40·09	3·75	..	19·27	20·87			
				Shafipur				
29·26	37·62	9·87	26·67	17·19	15·90	7·8	38·21	8·1
				Botany Farm (I. A. R. I.)				
35·80	41·63	9·14	15·70	19·29	19·16	13·00	31·01	7·9
31·93	33·86	8·90	26·14	15·77	16·73	10·92	45·67	8·2
33·15	43·37	10·20	15·47	17·87	16·60	15·89	30·88	8·2

days previously. Another sample (18/52) was taken from Plot No. 45, which was lying fallow. The previous crop was paddy. The texture of all the three fields was sandy loam.

Mechanical composition of surface soils. Data on the mechanical composition of these soils are loam, loamy sand and sandy loam. In Nangloi Jat village, the percentages of silt and clay varied to a small extent.

In the soils from the villages of Tilangpur, Rhenola, Narula, Shafipur and Botany Farm (I. A. R. I.), the relatively high proportion of sand made them appear light in texture even though the fine fractions in some cases were quite appreciable. There was comparatively higher percentage of coarse sand in the Botany Farm soils.

Single value physical constants of surface soils. Data on water holding capacity, pore space, sticky point and moisture equivalent are also given in Table VI.

The soils having a higher percentage of clay had higher water holding capacity than those having lesser amounts of clay. In general the values for the water holding capacity were somewhat higher in comparison to the values of clay due to the presence of sodium in exchange complex. Moisture equivalent values varied directly with the values of clay and percentages of exchangeable sodium.

Chemical constituents

Chemical composition of selected soils are given in Table VII and VIII.

TABLE VII

Mineral composition

Lab. No.	9/52	10/52	11/52	12/52	18/52	19/52
Insoluble silica	77·23	76·87	75·75	73·82	76·70	75·98
Sesquioxides	14·72	15·35	16·37	13·20	13·75	14·12
CaO	1·28	1·05	1·14	0·96	1·87	1·09
MgO	0·96	0·69	0·52	0·69	0·55	0·64
K_2O	0·54	0·94	1·36	1·03	1·44	1·09
P_2O_5	0·17	0·07	0·12	0·13	0·109	0·11

Table VIII

Loss on ignition and percentage organic carbon and total nitrogen

Lab. No.	Moisture	Loss on ignition	Organic carbon	Total nitrogen	C : N ratio
		Nangloi Jat			
596/51	0·88	3·78	0·427	0·053	8·05
597/52	1·08	3·42	0·380	0·049	7·75
598/51	0·92	3·54	1·002	0·089	11·25
		Tilangpur			
9/52	0·64	3·54	0·523	0·05	10·46
10/52	0·88	3·32	0·296	0·055	5·38
		Rhenola			
12/52	0·72	3·67	0·301	0·048	6·27
426/52	1·01	2·92	0·284	0·051	5·57
		Shajipur			
11/52	0·93	3·47	0·34	0·052	6·54
		Botany Farm (I. A. R. I.)			
17/52	1·37	3·17	0·482	0·059	8·17
18/52	1·05	3·91	0·504	0·057	8·84
19/52	1·08	3·24	0·555	0·057	[illegible]

It is evident that silica content was high in all the samples and was more or less uniform.

Water soluble salts. A study of the data in Table IX will indicate that the total soluble salt content varied from 40·18 per cent to 0·456 per cent in Nangloi Jat village. The calcium carbonate percentage was somewhat higher than in others. pH was above 8·0 in all cases showing alkaline characteristics of the soils. Bicarbonates were predominantly present in comparison to other acid radicals. Sodium predominated among bases. Nitrates were present in all cases in sufficient amounts.

The percentage of total salts was not so high as in sample No. 9/52 and 10/52 from Tilangpur as in Nangloi village samples. Calcium carbonate was less than 1 per cent in both the samples. Bicarbonates and sodium predominated among different acid and basic radicals. Nitrates and carbonates were totally absent. Chlorides and sulphates were present in sufficient quantities showing saline characteristics. In Rhenola village, the total soluble salt content in sample No. 12/52 was much higher than the sample No. 426/52. There was not such marked difference in pH and in the content of calcium carbonate. In Shafipur village sample No. 11/52 bicarbonates and chlorides predominated. The total salt content and calcium carbonate content were quite low.

The total soluble salt content was high in all the samples of Botany Farm. pH value ranged from 7·9 to 8·2. Calcium carbonate content was moderate except in sample No. 18/52. Chloride and sulphate predominated in almost all cases, while carbonate was totally absent. Sodium content predominated among the bases.

The exchangeable sodium percentage was nearly double in sample No. 10/52 than in sample No. 9/52. There was a wide difference in their degree of alkalisation as well. Ex. Na percentage was quite high in all the samples from Rhenola and Shafipur. In sample No. 18/52 from the Botany Farm the Ex. Na percentage was also high while in other two samples it was about 15 per cent.

From visual characters of these profiles, it could be concluded that these soils had a very scanty horizon differentiation which was characteristic of alluvial soils in other states of India as well [Glinka, 1927]. Marbut [1927] placed such soils in abnormal profiles. In many cases, however, evidence of the existence of textural horizon could be obtained [Mukerjee and Agarwal, 1947].

Earlier work [Tripathi, 1905] revealed that villages which were quite near the river Jumna had got a very low percentage of clay and higher percentage of silt due to annual deposits from the river. Moving further towards west and south heavier and comparatively older soils of sandy loam and silty loam to clay loam texture are generally encountered. Soils in *bangar* and *dabar* areas consist of old alluvium. The texture varied from sandy loam, loamy sand to loam and clay loam. The soils were found to be definitely heavier in texture in lower horizons in these areas. These facts show that the rainfall of the locality although scanty, could, nevertheless, permit slight eluviation of colloidal matter into the lower layers or the formation of a clayey layer *in situ* by hydrolytic decomposition and not through a process of eluviation as suggested by Nikiforoff [1957].

TABLE IX

Total soluble salts determined by conductivity and gravimetric methods, pH and $CaCO_3$
(results of analysis of water extract of surface soil samples)

Lab. No.	Total solid 105°C	Percentages								
		NO_3 per cent	CO_3 per cent	HCO_3 per cent	Cl per cent	SO_4 per cent	Ca per cent	Mg per cent	K per cent	Na per cent
Nangloi Jat										
596/51	0·429	0·056	0·004	0·165	0·023	0·092	0·009	0·017	0·003	0·099
597/51	0·418	0·042	0·002	0·123	0·048	0·071	0·007	0·007	0·005	0·104
598/51	0·456	0·065	..	0·083	0·066	0·089	0·014	0·009	0·006	0·110
Tilanypur										
9/52	0·175	..	..	0·088	0·012	0·017	0·001	0·003	0·001	0·042
10/52	0·147	..	..	0·086	0·014	..	0·001	0·004	0·001	0·032
Rhenola										
12/52	0·395	0·035	0·007	0·184	0·013	0·05	0·002	0·012	0·003	0·074
426/52	0·128	0·0006	..	0·078	0·002	0·01	0·0008	0·0008	0·001	0·034
Shafipur										
11/52	0·134	..	..	0·079	0·011	..	0·002	0·002	0·003	0·029
Botany Farm										
17/52	0·539	0·106	..	0·029	0·105	0·100	0·031	0·007	0·003	0·115
18/52	0·293	0·072	..	0·068	0·016	0·054	0·011	0·004	0·003	0·068
19/52	0·603	0·094	..	0·029	0·161	0·115	0·002	0·006	0·002	0·183

Soils situated in depression of *khadar* area also show heavier texture in lower horizons [Tamhane, Shome and Raychaudhuri, 1953, Nimgade, 1955, Sankaran, 1952]. The content of calcium carbonate had increased in direct relation to clay except in profile II from Excort's Farm, Azadpur [Sankaran, 1950].

Drainage in this area was generally unsatisfactory and water logging was a common feature. The *kankar* in the form of small nodules or larger concretions were found distributed irregularly from a depth of 3 ft. to 5 ft.

The occurrence of lime concretions either as a layer at certain depth or distributed throughout the profile was a well recognised characteristic of the soils of the arid and semi-arid region. Jenny [1941] has shown that the depth of the occurrence was chiefly conditioned by the precipitation of the area : this being 35 to 47 inches for an area with an annual rainfall of 25 inches. Mukherjee and Agarwal [1946-1947] noted presence of *kankar* in the soil of Unao and Sandila districts in U. P. Punjab soils were found to be impregnated with lime concretions by Hoon and Dhawan [1943] and Dalip Singh and Lal [1946]. The presence of a calcareous layer in saline and alkaline soils had also been pointed out by Puri [1949] as a general characteristic.

The presence of two layers of *kankar*, one at the top and other at a lower depth or its presence in the topmost layer alone, as evidenced by Basu and Tagare [1943] in Bombay, had not been marked here so far probably due to comparatively immature nature of the soils. The total soluble salt content was lowest in the surface samples and went on increasing with the depth, maximum being in the layer of $CaCO_3$ accumulation. Structure was generally undeveloped or cloddy to angular. It was interesting to note that the depth of *kankar* accumulation varied from 27 to 54 inches in different profiles. This confirmed the observations of Jenny (*loc. cit.*).

It is observed that in Delhi there is a high accumulation of soluble salts in the top layers in some soils while in the others the salt percentage accompanied by exchangeable sodium increased with the depth showing in some cases zone of accumulation. The distribution of $CaCO_3$ is sometimes quite irregular and in certain cases it accumulates in the form of *kankar* nodules.

The soils are primarily saline (solonchak) and are in the process of various degrees of salinisation or alkalisation due to leaching of saline constituents ; but have not reached the stage of non-saline alkali (solonetz) soils. The saline soils of Delhi can be grouped on world classification basis as of Interzonal order, halomorphic sub-order belonging to "Great Soil Group" Saline (Solonchak) and Saline--Alkali Soils [Baldwin *et al.*, 1938].

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SPREAD AND INTENSITY OF SOIL ALKALINITY WITH CANAL IRRIGATION IN GANGETIC ALLUVIUM OF UTTAR PRADESH

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(With 1 Text-Figure)

In connection with investigations on saline and alkali (*usar*) soils of Uttar Pradesh it is of interest to examine whether *usar* patches situated in arable land under irrigation have become worse after the introduction of canals. This question was under the consideration of the 'Reh Committee' appointed by the Government of India in 1877 ; but the Committee could not at that time give a precise answer to the question since on the basis of the then existing scientific evidence collected by them they could not decide if canal water was responsible for the creation, spread or intensification of *usar* patches in canal irrigated areas of the State. Leather [1914] took up the scientific study of this problem during 1910-12. He selected a line of country as similar as possible in respect of soil and hydrological conditions in the district of Etah where sterile *usar* patches occurred in arable fields. A number of such *usar* patches were selected by him which were accurately mapped to obtain a survey plan and soil samples were collected in sections of 6 inches, from each patch. The position in the patch from where soil samples were obtained was accurately marked on the survey plan. The survey maps of the *usar* patches, the position of the boring from where soil samples were obtained and other relevant data in connection with the location of the fields in which the patches occur, have been recorded by Leather [1914]. This was done so that a future comparison of the selected *usar* patches in the area and the soil analytical data, with their state as it existed in 1912, may enable a dependable decision as to whether canal irrigation caused extension in the area of the patches or increased the intensity of alkali in the soils. Leather desired that the patches selected by him be again examined after the fields had received canal irrigation for a period of 40 years so as to judge the effect on the *usar* conditions in the intervening period.

In accordance with the objective put forward by Leather in 1912 and since the relevant old records are available in these laboratories twelve randomly selected *usar* patches, out of 29 fixed originally by Leather, were revisited in 1952 after a lapse of 40 years, the patches were resurveyed and soil samples re-examined by precisely the same methods and techniques that were adopted by Leather. The results obtained in the course of the fields and laboratory studies made in 1952 are embodied in this article.

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Methods and Material

The land containing the *usar* patches lies in the Etah district on either side of the road from Jalesar Road railway station to Awakhas, a distance of about 20 miles. Being commanded by the Lower Ganges Canal the tract has been continuously under canal irrigation. Out of 29 patches demarkated by Leather, 12 patches were selected at the rate of three patches in four randomly selected villages. The field in which the patch occurred was located in the village with the help of the map recorded by Leather. In most of the cases a stone mark, with the number of patch and the boring engraved on it as fixed by Leather in 1912, still exist at the site. A plain table survey of the sterile *usar* patch was made and the survey plan so obtained was compared with the survey plan of Leather. The exact spot from where the soil samples were collected in 1912, as marked on the map, was then fixed carefully on the field and soil samples were collected from the same depths as those of Leather.

The exact area of the patch was obtained by tracing the two survey plans (1912 plan and 1952 plan) on a graph paper and counting the squares enclosed within. The area so obtained was expressed in square feet with the help of suitable, conversion factor. Soil samples were analysed for their water extract prepared on a 1 : 5 soil-water ratio. Anionic contents of the water extracts were estimated by analysing for carbonates, bicarbonates, chlorides and sulphates, as was done for 1912 samples by Leather. The results of the soil-water extract were expressed by Leather as per cent sodium salt of the anions. In the present investigation these have been expressed as milli-equivalents of individual anions per 100 gm. of the soil. Total ionic concentrations were obtained by adding the concentrations for individual anions. This method afforded a better appraisal of the total salt contents in the soil. For the sake of comparison, Leather's [1914] data were also recalculated and converted to the above basis.

Experimental

The morphological features of the soil and the sub-soils and the site characteristics, as observed in 1912 and again recorded in 1952, for the twelve patches are given in Table I. Analytical data for the water extract pertaining to the surface soil samples (0-6 in.) are presented in Table II. To obtain an overall picture of the salt status in the entire soil profile up to a depth of 30 inches the analytical results for the various soil depths have been averaged and the figures so obtained have been used to calculate their contents in the profile up to 30 inches. These figures have also been presented in Table II alongside the data for surface soils. For, assessing the total salinization in the soil profile represented by the area as the base up to a depth of 30 inches of the sterile patch, both in 1912 and in 1952, use has been made of the expression 'volume salt-concentration' and the total salt contents have been shown on volume basis in gram equivalents. This was calculated by multiplying the area with the conversion factor $\left(\frac{X \times 90 \times 450}{100}\right)/1000$, where X represents the total ionic concentration per 100 gm. of the soil and the

TABLE I

Morphology and site characteristics of the usar patches

Village	Boring number of Leather	Nature of *usar* patch	Area of sterile patch (sq. ft.)	Description	Nature of sterile patch	Area of sterile patch (sq. ft.)	Method of irrigation and distance from canal	Description	Water table
		1912 observations			1952 observations				
Bichpuri	22	Quite sterile	708	0 to 3 ft. soft soil; 3 ft. to 4 ft. 6 in. hard soil; *kankar* obtained from 3 ft. to 9 ft.	Sterile	936 (+32)	Flow 100 yds.	Surface soil loam; clayey loam at 18 in. depth; indurated layer present.	22 ft.
	23	Crop sown had stunted growth	640	3 to 6 ft. soil stiff; sandy at 8 ft.; small *kankar* nodules at 3 ft.	Less sterile	1972 (+208)	Flow 250 yds.	Clayey loam throughout; sub-soil is hard; small *kankar* nodules at 3 ft.	
	24	Sterile	720	0 to 5 ft. 6 in. soil hard clay; below sandy; *kankar* met with from 3 ft. 6 in. to 7 ft. 6 in.	Sterile	1116 (+55)	Lift 400 yds.	Loam at the surface; sub-soil heavier; indurated pan at 2 ft. depth.	
Unchagaon	25	Sterile	3648	0 to 3 ft. soil soft; below *kankar* met throughout.	Less sterile	3700 (+1)	Flow 200 yds.	Sandy loam at the surface; sub-soil only slightly heavier; *kankar* found within 3 ft. depth.	30 ft.
	28	Not entirely sterile	784	0 to 6 ft. soil soft and moist; below this large sized *kankar* found.	Sterile	1216 (+55)	Lift 100 yds.	Loam throughout; lower layers are slightly heavier than surface; large sized *kankar* present.	
	29	Crop sown had stunted growth	1072	Soil from 5 to 6 ft. contain *kankar*; excluded from future irrigation.	Less sterile	2404 (+124)	Flow 400 yds.	Sandy loam at the surface; indurated clay pan after 12 in.	
Punhera	45	Sterile	1912	Surface to 7 ft. 6 in. soil clayey; some *kankar* met with in 4th, 6th and 7th feet.	Less sterile	1932 (+1)	Flow 100 yds.	0 to 18 in. soil is loam to light loam; heavier at 2 ft. depth.	15 ft. summer
	46	Quite sterile	3664	0 to 3 ft. 6 in. soil hard and moist; below 5 ft. sandy; from 3 ft. 6 in. to 8 ft. 6 in. *kankar* found.	Quite sterile	9064 (+147)	Lift	Surface upto 12 in. is loam; heavier after this; hard pan at 2 ft. depth.	
	47	Sterile	300	*Kankar* present below 6 ft.	Less sterile	252 (—16)	Flow 200 yds.	Loam at the surface; underlain by a sandy loam soil.	
Gadesara	48	Sterile	2100	Loamy soil throughout; no *kankar*.	Less sterile	3092 (+47)	Lift main canal half mile	Sandy loam throughout; small calcareous nodules at 3 ft.	10 ft. summer
	49	Quite sterile	1696	Soil soft and moist throughout; *kankar* found below 8 ft. 6 in.	Quite sterile	1960 (+16)	Flow 150 yds.	Sandy loam throughout.	
	50	Sterile	352	*Kankar* present in 7th and 8th ft.	Sterile	988 (+181)	Flow	Sandy loam at the surface; lower layer sandy.	

NOTE.—Figures in parenthesis indicate per cent increase or decrease over the original area.

TABLE II

Composition of the (1:5) water extracts from the soils of usar *patches in 1912 and 1952*

Village	Leathers boring No.	pH (0-6 in.) in 1952	Saturation percentage (0-6 in.) in 1952	1912 Values (m.e. per 100 gm.)								1952 Values (m.e. per 100 gm.)							
				0-6 in.				0-30 in.				0-6 in.				0-30 in.			
				CO_3 + HCO_3	Cl	SO_4	Total ions	CO_3 + HCO_3	Cl	SO_4	Total ions	CO_3 + HCO_3	Cl	SO_4	Total ions	CO_3 + HCO_3	Cl	SO_4	Total ions
Bichpuri	22	7·8	34	0·83	0·17	0·00	1·00	1·89	0·34	0·25	2·49	0·50	0·32	0·00	0·82	1·86	0·24	0·14	2·24
	23	7·7	44	0·97	0·17	0·00	1·14	1·45	0·31	0·00	1·76	0·52	0·13	Tr	0·65	1·39	0·16	Tr	1·55
	24	9·6	33	0·95	0·12	0·00	1·07	1·38	0·34	Tr	1·72	1·82	0·22	Tr	2·04	2·60	0·34	0·18	3·12
Unchagaon	25	9·5	29	0·25	0·19	0·00	0·44	1·04	0·59	Tr	1·64	1·30	0·22	0·17	1·69	2·25	0·38	0·24	2·87
	28	8·7	34	1·00	0·12	0·00	1·12	0·85	0·24	Tr	1·09	0·88	0·19	0·28	1·35	1·75	0·41	0·33	2·49
	29	9·2	31	1·10	0 23	0·00	1·33	1·04	0·32	Tr	1·36	1·14	0·12	0·11	1·37	1·74	0·25	0·18	2·17
Punhera	45	9·0	36	1·60	0·16	Traces	1·76	2·50	0·27	0·21	2·97	1·18	0·24	Tr	1·42	2·41	0·26	0·19	2·86
	46	8·6	37	2·29	0·32	Traces	2·61	3·13	0·48	Tr	3·60	0·92	0·17	0·00	1·09	1·27	0·28	Tr	1·55
	47	9·5	37	0·89	0·32	Traces	1·21	1·47	0·67	0·43	2·57	1·60	0·47	0·28	2·35	2·30	0·93	0·82	4·05
Gadesara	48	10·0	28	2·41	0·23	Traces	2·64	2·73	0·21	Tr	2·94	1·86	0·18	0·18	2·22	2·93	0·25	0·31	3·49
	49	10·0	29	2·33	0·16	Traces	2·49	3·19	0·27	0·24	3·70	1·44	0·14	0·36	1·94	2·17	0·26	0·39	2·82
	50	9·4	34	1·65	0·16	Traces	1·81	1·78	0·22	0·08	2·08	1·24	0·22	0·49	1·95	2·40	0·24	0·67	3·31

figure 90 represents the weight in pounds of one cubic foot of the soil in question. The area of the sterile patches and the volume salt-concentrations for 1912 and 1952 have been shown separately in Table III. In Table IV are given the average composition of irrigation waters of Lower Ganges Canal used in the fields for the 40 years, as reported by the authors in earlier publications [1952, 1953].

In order to illustrate the spread of the *usar* patch on the survey plan, the 1912 map as prepared by Leather and the 1952 map as now prepared, are given for one patch only in Fig. 1. Relevant data in respect of other patches are embodied in the Tables.

It can be seen from the data given in Table I that the general effect to prolonged use of canal irrigation waters has been one of increasing the area of sterile patches. Out of the twelve fields examined which received canal irrigation for 40 years, and more, area of sterile patch has increased appreciably in as many as nine fields, the variation in area in the other two fields showed only minor increase and in one case slight decline was observed. Total soil salinity expressed as total ionic concentration has not shown increase in the same proportion as the increase in area (Table II). Actually total salinity in surface soils, has increased and decreased evenly in six-fields, the increase being more marked in village Unchagaon where all the three fields showed greater proportions of salts. In village Bichpuri such increase was observed only in one field, the other two showed some decline. Surface salt concentration in each of the other two villages, viz. Punhera and Gadesara, has decreased in two fields and increased in the third. The values for the total dissolved salt, in column of soil 30 inches deep, reveal more or less similar trends, as shown by the surface values, with the only exception in one field in village Gadesara where the present average values are higher than those recorded in 1912. The changes in soil salinity have been reflected primarily in carbonate and bicarbonate ions with very little difference in the status of chloride and sulphate concentration.

The ionic concentration for the entire volume of soil expressed by the term volume-salt-concentration, as given in Table III, shows that the salt contents have increased in 10 out of 12 fields in the 30 inches soil column. Maximum increase has been recorded again in village Unchagaon followed by that in village Bichpuri and Gadesara and the least in Punhera.

Discussions

Amongst the chief agencies responsible for soil salinisation the quality of irrigation waters is believed to play a very prominent part although soil factors are also of considerable importance. These factors are : soil minerals, sub-soil compaction, drainage, permeability of the entire soil strata, soil management practices, etc. Whenever any of these factors alone or in combination with other factors, favour the process of soil salinisation, salinity conditions in the soil slowly develop. The quality of canal irrigation waters of Uttar Pradesh has been described by Agarwal, Mehrotra and Gangwar [1955] to be of a fairly safe nature. In terms of the categorisation of water quality as proposed by the U. S. Salinity Laboratory [1954], these waters can present only medium salinity

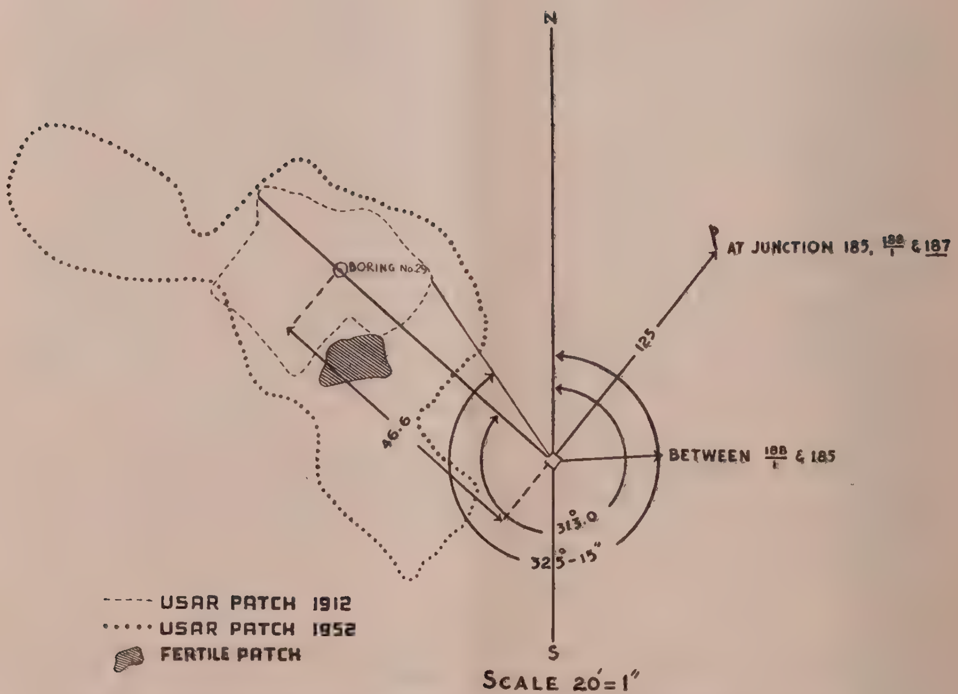

FIG. 1. Survey plans of *usar* patches in village Unchagaon, District Etah, (U.P.)

TABLE III

Area and volume-salt-concentration of usar *patches in 1912 and 1952*

Village	Boring Number	1912					1952				
		Area (sq. ft.)	Volume-salt-concentration gm. equivalent		Total for the village		Area (sq. ft.)	Volume-salt-concentration gm. equivalent		Total for the village	
			Surface 0-6 in.	30 inches column	Area (sq. ft.)	Volume-salt-concentration 30 inches column		Surface 0-6 in.	30 inches column	Area (sq. ft.)	Volume-salt-concentration 30 inches column
Bichpuri	22	708	143	1785			936	156 (+8)	2123 (+19)		
	23	640	148	1140			1972	260 (+76)	3095 (+171)		
	24	720	156	1254	2068	4179	1116	461 (+196)	3526 (+181)	4024	8744
Unchagaon	25	3648	325	6057			3700	1266 (+289)	10752 (+78)		
	28	784	178	865			1216	332 (+87)	3066 (+254)		
	29	1072	289	1476	5504	8398	2404	667 (+131)	5282 (+258)	7320	19100
Punhera	45	1912	681	5750			1932	556 (—18)	5595 (—3)		
	46	3664	1937	13355			9064	2001 (+3)	14225 (+7)		
	47	300	74	781	5876	19886	252	120 (+62)	1033 (+32)	11248	21853
Gadesara	48	2100	1123	6251			3092	1390 (+24)	10926 (+75)		
	49	1696	855	6354			1960	770 (—10)	5596 (—12)		
	50	352	129	741	4148	13346	988	390 (+202)	3311 (+347)	6040	19833

NOTE.—Figures in parenthesis indicate per cent increase or decrease in the volume-salt-concentration after a lap se of 40 years.

TABLE IV

Average composition of waters from lower Ganges canals in Etah District

	pH	$E.C \times 10^6$	Anions m.e/1				Cations m.e/1			Total ionic contraction m.e/1	Water quality
			CO_3	HCO_3	Cl	SO_4	Ca	Mg	Na		
Lower Ganges Canal	8·72	365	0·13	2·03	0·24	1·35	1·78	0·44	1·54	3·76	C 2-S1

hazards. Carbonate and bicarbonate ions (Table IV) in these waters being together equal to or less than the divalent cations, the waters could not be expected to leave any residual alkalinity, as postulated by Eaton [1950]. On the basis of the standards put forwarded by Wilcox, Blair and Bower [1954], the carbonate and bicarbonate contents of the irrigation waters were also not likely to increase soil alkalinity. But even with such a good quality of irrigation waters, there had been both spread and intensification of alkali in the *usar* patches examined, during a period of 40 years. Evidently, factors other than the quality of irrigation waters have been responsible for this state of affairs.

Out of the four villages the area has increased most in village Gadesara where water table now stands quite high even during the dry months. This increase in area is not necessarily correlated by a simultaneous change in salt concentration which has actually decreased in two and increased in one field. However, the interaction between volume and ionic concentration, expressed in terms of gram equivalents, shows a net increase in two of these fields in boring Nos. 48 and 50 to the extent of 24 and 202 per cent. The third field has shown a decline but this is not very significant. Trends in 30 inches soil column had been almost similar to those at the surface. Possibly, high water table had been most effective in the field of boring No. 50 and least in 49 where fair degree of leaching seems to have taken place. Field with boring No. 48 has a layer of small calcareous nodules at about 3 ft. depth which presumably accounts for the increase in soil salinity by obstructing free drainage.

The area in Bichpuri village has increased in all the three fields and like Gadesara ionic concentration has increased only in one field showing no relationship between the two factors. Total volume-salt-concentration in the *usar* patch, both for the surface as well as the 30 inches soil column has, however, increased in all the three fields and this effect is more prominently displayed in the data of the entire soil column. The absolute increase in values of salts in the three fields for the surface soils is 8, 76 and 196 per cent over the 1912 values. This increase is in direct relationship with the presence of indurated layer, which in some of these fields consists of *kankar* (lime carbonate) nodules of varying sizes. In the first field indurated layer consists of only a clay pan, the second field having small *kankar* nodules while the third possesses an indurated layer of *kankar* only at two feet depth and is responsible for maximnm salinisation.

Greatest increase in salinity has been noticed in Uchagaon village though not in the same order as increase in area. This general increase varied to the extent of 289, 87 and 131 per cent in the surface and 78, 254 and 258 per cent in the 30 inches soil column over the 1912 values and can be attributed also to the *kankar* pan present in field Nos. 25 and 28 which checks water percolation and leaching. The salinisation in these fields is thus the result of natural alkalisation of the soil rather than the use of canal waters which accounts for very little salts as compared to the actual increase. The field with boring No. 29 was highly alkalised even in

1912 and, therefore, had then been recommended to be excluded from further irrigation and the increased salinity of this field may not be difficult to explain. This village is a representative example of the typical saline-alkali areas of this state and seem to have little correlation with the quality of canal irrigation waters.

Soil salinisation had been least marked in village Punhera where neither the area nor the ionic salt contents have increased as markedly as in other villages. The intensity of area in this village has increased only in the field with boring No. 46 but even that has not shown a simultaneous increase in salt concentration per 100 gm. of soil. Values of volume-salt-concentration, however, have exhibited somewhat different picture of salinisation. This has decreased by about 18 per cent in the surface layer and 3 per cent in the 30 inches soil column in field containing boring No. 45 while the other two fields have shown some increase. Boring No. 46 recorded an increase of only 3 and 7 per cent while boring No. 47 showed increase of 62 and 32 per cent. These values thus indicate little change in the salt status of the first two borings but a significant increase in the third. The soil formation of this village is of a mature type where natural internal drainage is adequate and soil fairly permeable. Water table is at medium depths in the neighbourhood of about 15 ft. Salt accumulation in these profiles thus appears only in adverse local conditions. This phenomenon is displayed in the third profile where some impedance in the subsoil layer is visible and may account for the increase in soil salinity during prolonged and continuous use of canal waters.

It can be inferred from the above discussion that there had been a general increase in total salinity in the area of study during the past 40 years in spite of the superior quality of irrigation waters. But this increase can hardly be attributed to the water quality because the amount of salt added in 30 inches soil column through canal irrigation at an average depth rate of 12 inches of water per acre annually would account for only a fraction of the actual salinisation noticed in many of the examined sites. Nearness of water table and impedance in the downward movement of water due to the presence of an indurated layer in lower depths seem to be the chief cause of increase in salinity.

Summary

Systematic investigations, on the question whether canal waters were responsible for the creation, spread or intensification of *usar* patches in canal irrigated areas of the State, initiated by Leather in 1912, were again taken up after a lapse of 40 years. Profile soil samples from 12 randomly selected sites out of a total of 29 and from precisely the same spots where Leather had carried out his investigations in 1912, were recollected in 1952 with the help of the survey plans and reference points left by the earlier author. New survey plans showing the present area of the *usar* patches were prepared with a view to compare them with the 1912 plans. The area of the *usar* patches was calculated for this comparison. Soil samples were examined for their 1 : 5 soil-water extracts in the same manner as done by Leather estimating the anionic constituents only. The 1952 values were compared with the values in 1912 after expressing or reconverting them in terms of milli-equivalent

per 100 gm. of soil. For making precise comparison use of expression volume-salt-concentration denoting total salt contents in gram equivalent on volume basis has been made. Some other estimations in salinity investigations such as saturation percentage and *p*H were also made.

It has been observed that the area of sterile patches has increased in nine out of 12 fields examined in the present work, but soil salinity expressed as total ionic concentration has not shown similar trends. A consideration of the interaction of the two factors, viz. area and ionic salt concentration expressed as volume-salt-concentration showed increases in ten sites and decline in two. The intensity of increases or decreases together with the causes of these changes have been discussed.

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PRE-IRRIGATION SOIL SURVEY OF SOME DISTRICTS OF THE PUNJAB

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(With 4 Text-Figures.)

PUNJAB extends over an area of about 46,000 square miles and may divided into the following regions :

North-eastern mountainous region

It consists of slopes and valleys of the parallel ranges of the Himalayas and the Shiwalik hills.

Plains

These consist of alluvial soil brought down by the various rivers and their tributaries. On the basis of the rainfall the plains can be sub-divided into three parts :

Sub-montane tract

Eastern plains

Western plains

The sub-montane tract usually receives about 35 inches of rain. The rainfall in the rest of the plains is, however, scanty and varies from 10 to 25 inches.

With the scanty rainfall, arid climatic conditions have developed in the plains of the Punjab. January and June are the coldest and the hottest months of the year respectively.

Soils

The province consists of hilly region and plains. The hilly soils are acidic to neutral in reaction and contain little soluble salts. The plains consist of alluvium and on account of arid climatic conditions prevailing in this part, a copious accumulation of the salts occur, and decidedly alkaline conditions have developed. *Kankar* (nodular calcium carbonate) formation has also taken place at most of the places.

LEGEND

S No.	NAME OF TRACT	AREA IN ACRES
1	RORI CHATALA	5,55,000
2	RANGOI TOHANA	3,83,400
3	SOUTH OF FATEHABAD SIRSA	3,72,600
4	BARWALA EXTENSION	1,92,600
5	SOUTH WEST OF HISSAR	72,000
6	WEST OF PEHOWA	4,82,400
7	KHANNA SAMRALA	1,92,600
8	LUDHIANA JAGRAON	1,75,800
9	GREY CANAL	4,66,800
10	BIST DOAB TRACT	4,11,000
		TOTAL = 33,04,200

FIG. 1. Index plan showing areas surveyed in the Punjab

The soils exhibit much diversity in properties. They are heavy soils, medium textured soils and sandy soils and are charged with salts in varying degrees. The main types are the following:

Solon-chak

Saline soils, containing sodium carbonate (black alkali) or sodium sulphate and sodium chloride (white alkali).

Solonetz

Alkaline soils, belonging to high *p*H and low soluble salt content type.

Soil Survey

The object of the soil survey was to determine:

(a) The character of the soil to be irrigated,

(b) The possible effects of surface irrigation when canal water becomes available,

(c) The quality of irrigation water,

(d) Proposed methods of reclamation.

The total area surveyed (comprising Karnal, Ambala, Ludhiana, Hissar, Ferozepur and Jullundur) is a little over 33 lacs acres. One profile from every 600 acres was taken. Soil sampling was carried out up to 10 feet depth from the natural surface and soil samples were taken from every foot section.

About 180,000 acres lying in Karnal and Kaithal Tehsils of the Karnal District were also surveyed. In this case, each profile represented approximately 400 acres. A number of profiles were also exposed up to water table at selected sites on each type of land. From these water-table profiles, moisture samples were collected for obtaining an idea of the moisture gradient and the probable depth of salt zone under pre-irrigation conditions. A few water samples were also collected from the different tracts in order to judge their quality for irrigation purposes.

The total area surveyed is not compact and can be divided in general terms into the following ten tracts situated in different districts of the State:

Name of the tract	District
Rori chautala tract	Hissar
Rangoi Tohana tract	Hissar
South of Fatehabad and Sirsa tract	Hissar
Barwala Extension tract	Hissar
South-west of Pehowa tract	Hissar
West of Pehowa tract	Karnal and Ambala
Khanna Samrala tract	Ambala and Ludhiana
Ludhiana Jagraon tract	Ludhiana
Grey canal tract	Ferozepur
Bist Doab tract	Jullundur

The classification of the areas belonging to each tract is given in Table VIII.

Methods

The soil samples were analysed for the following :

Kankar (nodular calcium carbonate)

The soil samples were air-dried, weighed and lightly powdered. The powdered samples were sieved through 2 mm. sieve. What remained on the sieve was washed free of soil with distilled water, dried in the oven and weighed. The percentage of *kankar* was calculated from the total weight of the soil initially taken for powdering. In samples which contained gravel, the residue on 2 mm. sieve was treated with hydrochloric acid, washed, dried and weighed. The weight of gravel was subtracted from the total weight of the gravel plus *kankar* and the percentage of *kankar* determined on the total weight of the soil as mentioned above.

p*H*. *(1:10 soil : water suspension)*

The *p*H values were determined with the Beckman glass-electrode.

Total soluble salt content

The total soluble salts were determined by the conductivity method [Hoon, Malhotra and Jain 1941].

The experimental technique consists of preparing a standard soil suspension (1 part of soil and 15 parts of distilled water), shaking it for about two hours on the shaking machine and determining the electrical conductivity of the soil suspension with the Dionic water tester. The percentage soluble salt content of the soil is calculated by dividing the conductivity of 1:15 soil water suspension by one thousand :

$$\text{Total salt percentage} = \frac{\text{conductivity}}{1000}$$

Clay content (particles below 0·002 mm.)

A few selected profiles were also examined in detail for their mechanical as well as chemical constituents.

The dispersion was carried out by using a mixture of sodium carbonate and sodium hydroxide [Puri 1936].

Calcium carbonate

The calcium carbonate content was determined by titration with standard sulphuric acid, using bromo-thymol-blue as indicator [Puri 1930].

Exchangeable bases

(a) Exchangeable sodium plus potassium was determined by shaking with normal ammonium carbonate solution for two hours, filtering, evaporating an aliquot portion out of the filtrate, adding known volume of standard Hcl and titrating the excess of the acid against standard alkali [Puri 1935].

(b) For exchangeable calcium, the soils were treated with a standard solution of normal potassium acetate (or potassium chloride) $\frac{N}{10}$ potassium oxalate and 0·015 normal potassium carbonate and allowing the reaction to proceed for about half an hour below 10°C. An a iquot portion out of the filtrate was titrated with standard potassium permanganate [Puri 1936].

Humus was determined by digesting the soils, with standard alkaline potassium permanganate, making the solution to known volume, filtering, taking an aliquot portion out of filtrate, adding known quantity of standard oxalic acid, and back titrating with standard potassium permanganate.

1 cc of norma l potassium permanganate consumed =3·9 milligrams of humus [Puri 1937].

Nitrogen was found by Kjeldahl's method as modified by Bal [1925]. The digestion with sulphuric acid was carried out in the presence of potassium and copper sulphate.

The phosphates were extracted from soils by passing carbondioxide in soil suspensions cooled in ice [Puri and Asghar 1936] and Deniges Technique as elaborated by Chapman [1932] was used to develop colour (ammonium molybdlnate and stannous chloride) and the intensity of the blue colours developed was measured by Klett Colorimeter against colours attained with standard phosphate solutions.

Data and Discussion

Standards for soil fertility and deterioration

The *p*H value and total soluble salt contents are the two important factors, which need specific control for maintaining the fertility of a soil. Taylor [1940 *loc-cit*] had specified the limits of fertility and deterioration of soils with special reference to *p*H and total soluble salts.

An excellent index of the stage of salinisation is the *p*H value. Whenever the *p*H value is not above 8·2 to 8·4, the *solon-chak* does not contain sodium carbonate and the soil is in a stage of salinisation. In soil surveys of waste lands, the limit of *p*H value was kept at 9·0 for the purposes of determining the advisability of new irrigation projects. Soils containing salts higher than 0·2 per cent, *p*H value greater than 9·0 and clay content more than 17·9 per cent were recommended for reclamation.

Physico Chemical Properties of Punjab Soils

Karnal and Kaithal tract

A study of the analyses of soils of Karnal district revealed certain peculiarities of the soils of that area. These are discussed below :

Total salt content

The total soluble salt content is one of the important factors, which need specific control for maintaining the fertility of a soil. Taylor [1940] had specified that soils containing more than 0·2 per cent total soluble salts needed reclamation. The soil

of the tract is alluvium over-lying sand layers. High salt content is a general feature of the area. It either exists throughout the depth of the soil profile or is found in the form of one or more zones of accumulation of varying thickness.

The predominant salt is sodium carbonate and sodium bicarbonate. The results of analysis of two typical salt scrappings are given in Table I.

TABLE I

Variation of nature of soluble sodium salts in salt scrappings

Nature of salt	Quantity
Total salts	22·8 per cent 17·0 per cent of the weight of soil
Sodium carbonate	48·3 per cent 21·0 per cent
Sodium-bicarbonate	33·4 per cent 60·6 per cent of total salts
Sodium sulphate	13·33 per cent 13·7 per cent
Sodium chloride	3·86 per cent 4·5 per cent
Sodium nitrate	No indication

It has been observed in Karnal soils that either the degree of alkalisation decreases with the depth or there is practically no change in its value. The results of analysis of two typical Karnal profiles are given in Table II.

TABLE II

Degree of alkalisation of Karnal soils with depth

Description	Depth in feet	Degree of alkalisation, *i.e.*, $\frac{Na+K\times 100}{Na+K+Ca+Mg}$	pH
Bahauli site	0-1/2	95·2	10·3
do.	1/2-1	90·5	10·3
do.	1/-2	90·9	10·4
do.	2-3	88·7	10·3
do.	3-4	66·4	10·2
do.	4-5	58·9	10·1
do.	5-6	44·9	9·4
do.	6-7	26·9	9·1
do.	7-8	32·2	9·05

TABLE II—*contd.*

Degree of alkalisation of Karnal soils with depth

Description	Depth in feet	Degree of alkalisation *i.,e.,* $\frac{Na+K\times 100}{Na+K+Ca+Mg}$	pH
Bahauli site	8-9	49·0	8·95
do.	9-10	38·3	8·9
V. Gondar	0-1	56·7	9·5
do.	1-2	82·1	10·2
do.	2-3	83·0	10·0
do.	3-4	72·1	10·1
do.	4-5	86·4	10·0
do.	5-6	56·5	10·1
do.	6-7	95·8	10·0
do.	7-8	82·9	10·1
do.	8-9	64·7	10·1
do.	9-10	Missing	10·0

According to Puri [1933], in soils with degree of alklisation less than 25 per cent crop yields would not be affected, between 25 per cent to 75 per cent there was an inverse linear relationship between that characteristic and the yield and beyond 75 per cent the crop yield would be greatly diminished.

The explanation of the decrease in the value of the degree of alkalisation is not far to seek. Calcium sulphate or calcium chloride formed in the reactions between sodium sulphate and sodium chloride and calcium carbonate by double decomposition begin to percolate down during rainfall or floods. The chances are that the divalent ions compete successfully with the monovalent Na and K ions for positions in the exchange complex and the result is that there is a corresponding decrease in value of the degree of alkalisation.

In the profile taken from Gondar village, there is not much difference in the degree of alkalisation with depth except in the sixth foot. On examination it has been found that there is practically no sodium sulphate or sodium chloride in the total soluble salt content of this profile. This factor also accounts for the high degree of alkalisation.

p*H value*

The second controlling factor in soil fertility is *p*H which according to Taylor [*loc. cit.* 1940] should be below 8·5. But in soil surveys of waste lands the limit of *p*H value was kept at 9·0 for the purposes of determining the advisability of new irrigation projects.

Karnal soils are alkaline in reaction. In majority of profiles, pH value is higher than the desired limit, viz. 9·0. Leaching coupled with green manuring will have to be adopted for the reclamation of such types of soils.

Clay content

The clay content of 258 profiles representing 103,500 acres is greater than 17·9 per cent throughout the depth of the profiles at certain depths. The high clay content is associated with either high pH, high total soluble salt content or both. In areas containing clay content more than 17·9 per cent, there is a possibility of the creation of false water-table. Drains will have to be provided for nullifying this effect. Green manuring is recommended for increasing the porosity of the soil.

Kankar (*nodular calcium carbonate*) *percentage*

There is only a small number of profiles which are free from *kankar* (nodular calcium carbonate) at some depths. In some cases it is as high as 50 to 68 per cent.

Summarising the above results, the total area in Karnal and Kaithal Tehsils can be classified as follows :

Classification	Area in acres		
	Kaithal	Karnal	Total
Total area surveyed	38,800	132,400	171,200
Area having only high total salts	8,400	4,800	13,200
-do- pH	1,600	7,600	9,200
-do- both high pH and total salts	11,600	101,600	113,200
Area having both low pH and total salts	17,200	18,400	35,600
Total	38,800	132,400	171,200
Area having high clay content	12,800	90,800	103,600
Area having low clay content	26,000	41,600	67,600
Total	38,800	132,400	171,200

Areas falling under heads 2, 3 and 4 need reclamation. 155,600 acres or approximately 79·2 per cent of the total area surveyed is in different stages of deterioration out of which 113,200 acres have almost completely gone saline.

It has been stated above that the general classification of each tract is shown in Table VIII. The results of detailed analysis belonging to each tract are discussed below seriatum.

Rori Chautala tract

The total area of this tract is 683,346 acres. But the soil samples have been taken from area representing 35,500 acres, out of which 348,600 acres can be put directly on normal cropping system based on the availability of water. Sodium sulphate and sodium chloride are the principal salts of the profiles. There are two types of soils found in this area :

(a) Loam to clay loam,
(b) Sandy

Great care is to be exercised in developing latter type of soils as there is a great seepage due to their sandy nature. The size of the plots has to be decreased for allowing the water to reach all the four corners of the field. Frequent dressings with green manuring are also needed for keeping up the level of fertility.

Rangoi-Tohana tract

On the basis of mechanical analysis of soils, this tract can be divided into three types :

(a) Loam

(b) Clay loam or clayey

(c) Sandy

It may be pointed out that the above nomenclature is based on Reynolds and Proto-papa-dakis [1948] classification.

The depth of water varies from 18 to 120 feet from the natural surface. Near Ghaggar the monsoon fed river, the water-table is comparatively high.

Generally the quality of soil of this tract appears to be good, as in years of good rainfall gram and barley give as high yields as 15-20 maunds per acre, and the wheat sown on wells gives an out-turn of 20-30 maunds per acre. The detailed analysis of a typical profile of this tract is given in Table III.

TABLE III

Detailed analysis of Rangoi-Tohana tract profile

Depth of profile	pH	Total salts Per cent	Calcium carbonate Per cent	Degree of alkalisation	Humus and nitrogen in milligrams per 100 gm. of soil	
1 ft.	8·7	0·28	2·15	10·5	239	74·0
2 ft.	8·7	0·20	1·5	11·0	560	78·0
3 ft.	8·7	0·22	1·5	9·6	245	58·0
4 ft.	8·7	0·27	1·2	11·2		
5 ft.	9·0	0·28	0·3	14·4	..	..
6 ft.	9·0	0·28	0·3	15·7	..	..
7 ft.	9·5	0·20	0·8	12·3	..	..
8 ft.	9·5	0·16	9·9	8·8	..	..
9 ft.	9·0	0·22	0·5	11·1	..	..
10 ft.	9·5	0·18	1·5	8·1	..	..

Village—SHAHPUR-BEGU

Tehsil—SIRSA

Distt.—HISSAR

Block—K 12

Sheet—8

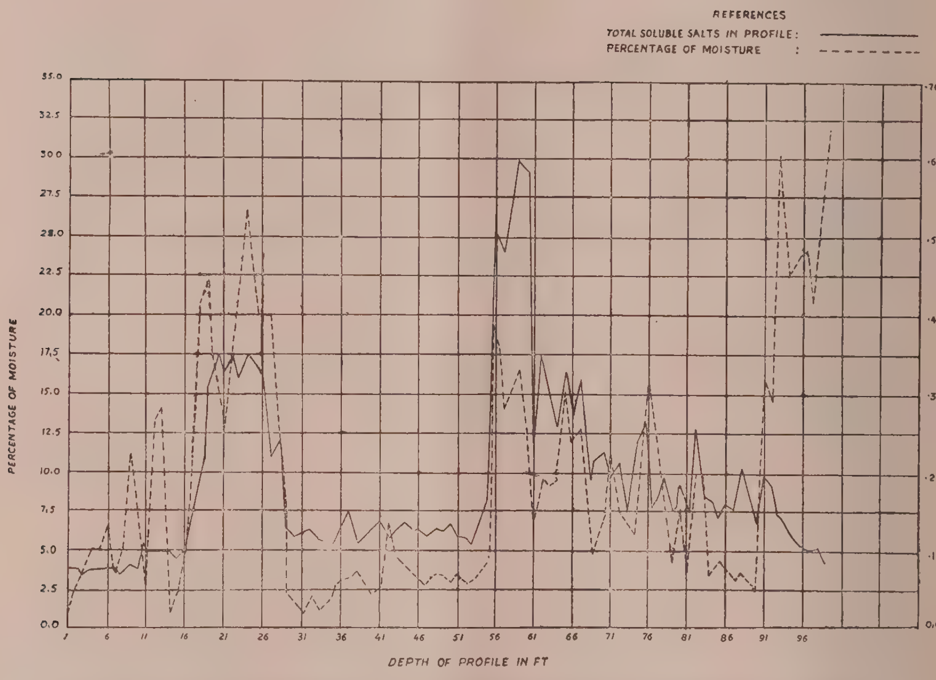

FIG. 2. Graph showing variations in total soluble salts with depth in Shahpur Begu village.

Apart from the presence of high total soluble salts in the top six feet and the high pH value from 7th to 10th feet the degree of alkalisation is below 25·0 per cent which shows clearly that the exchange-complex has not yet been affected by the sodium ion. It has been already established by Puri [1934] that if the degree of alkalisation is below 25·0 per cent the yield of crop is normal. Such types do not require more than one rice crop followed by some leguminous crop [Asghar and Dhawan 1927]. The variation in exchange capacity follows the changes in clay content.

South of Sirsa and Fatehabad tract

The total area of this tract is 375,902 acres, generally the soil is very light, 372,600 acres have been analysed; 108,000 acres are found to be excessively sandy. Sand dunes varying in size and height are scattered, some of them being as high as 30 feet.

The water table is 90-120 feet. Water table profile was exposed in Shahpur-Begu village. The variation in total soluble salt with depth is represented in Fig. 2, which shows that with the exception of certain depths high salts are present, right up to the last foot of the profile in the form of several zones of salt accumulation. The water is mostly unsuitable for irrigation purposes.

About 54·0 per cent of this tract is fit for normal cultivation.

Barwala extension tract

The total area of this tract is 147,576 acres, spreading over Hansi and Fatehabad Tehsils of Hissar District.

Soils of this belt are sandy at the surface but lower down they are loamy. Sand dunes varying from 15 to 40 feet in height cover an approximately 10,000 acres. These dunes should be cultivated *barani* (without irrigation but depending upon rain only) for crops like gram and melons in years of timely rainfall.

For increasing the water holding capacity of the sandy soils and also furnishing them with the necessary nutrients suitable type of green manuring is to be recommended.

The water table in this tract varies from 80-120 feet. A water table profile was exposed up to a depth of 120 feet in village Barwala and the results of the variation in salt content with depths are given in Fig. 3. The results show that high salts are present in several zones of salt accumulation of variable thickness. The water is in most cases unsuitable for irrigation purposes. These factors are to be taken into consideration while recommending the cropping schemes for such areas.

South-west of Hissar District

The area of this tract is 74,803 acres lying south-west of Hissar. Only 19.16 per cent need reclamation. Thirty per cent is sandy and 50·83 per cent can be directly placed under normal cropping schemes. As recommended in the previous tract, the sandy and high alkaline soils need some form of green manuring. Green manuring not only increases the water holding capacity of the soils but also reduces the alkalinity.

Village—BARWALA

Teh. & Distt.—HISSAR

Block—M12

Sheet—189 No. 12

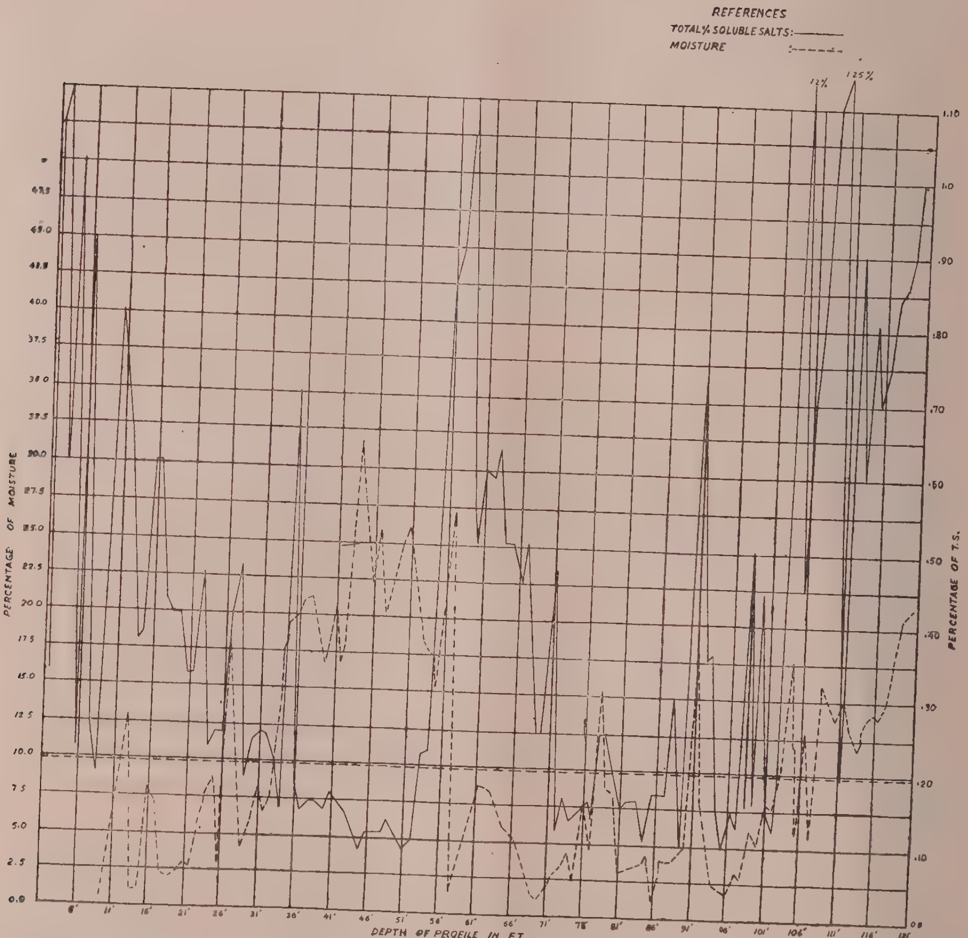

FIG. 3. Graph showing variations in total soluble salts with depth in Barwala village.

The depth of water table varies from 80 to 90 feet. The quality of sub-soil water is unsuitable for irrigation.

West of Pehowa tract

The tract comprises culturable waste lands of Kaithal and Thanesar Tehsils of Karnal District. The total area of this tract is 482,400 acres, out of which about 44·0 per cent need reclamation.

The physico-chemical properties of Kaithal and Karnal Tehsils have already been discussed in detail. The properties of Thanesar soils are similar. They require the same treatment as suggested under Karnal soils.

The water table varies from 0 to 37 feet. Most of the water samples are good for irrigation.

Khanna-Samrala tract

The total area is 168,632 acres out of which only 14·0 per cent are under different stages of deterioration.

The depth of soil crust varies from 0 to 8 feet. Excessively sandy soils having no or little soil crust are locally known as *bhudi*. They are most suitable for groundnut cultivation.

The results of analysis of a typical profile are given below :

TABLE IV

Detailed chemical analysis of Khanna-Samrala profile

Depth	pH	Total salts Per cent	Calcium carbonate Per cent	Degree of alkalisation	Humus and nitrogen in milligrams per 100 gm. of soil	
1 ft.	8·9	0·05	0·51	22·2	173·4	40·6
2 ft.	8·6	0·06	0·5	18·0	272·0	42·0
3 ft.	8·2	0·05	0·5	20·5	208·6	39·2
4 ft.	8·2	0·05	0·5	15·6	..	..
5 ft.	8·3	0·05	0·5	10·9	..	..
6 ft.	8·3	0·05	0·5	13·3	..	..
7 ft.	8·2	0·05	0·5	10·7	..	..
8 ft.	8·2	0·05	0·8	11·5	..	..
9 ft.	8·7	0·06	0·8	11·4	..	..
10 ft.	8·9	0·06	1·0	13·7	..	..

It has been observed that though the degree of alkalisation is below 25·0 per cent, yet the yields are not normal.

This is probably due to the low quantity of nitrogen and humus present in the soil. These soils also require green manuring for maintaining the proper fertility of the soil which will ultimately increase the yield of the crops.

The water table of the area varies from 6 feet to 35 feet and the sub-soil water is fit for irrigation.

Ludhiana Jagraon tract

In this area also only about 14·0 per cent require reclamation. Due to the sandy nature of the profile, the reclamation will be quick and easy. The physico-chemical properties of these soils are similar to that described under Khanna-Samrala tract.

The water table varies from 6 feet to 35 feet and the sub-soil water is suitable for irrigation.

Grey canal tract

The total area of this tract is 425,000 acres. It is served by a network of inundation canal known as grey canals.

It is subject to floods from river Sutlej. The water table varies from 0 to 4 feet and the sub-soil water is fit for irrigation.

In this area both high salts and high *p*H values are found either separately or jointly (Table I). The predominant salt is sodium sulphate or sodium chloride.

Here the problem is two-fold. Not only the soils are infested with either high salt content or high *p*H value, but the water logging also merits immediate attention.

Bist Doab tract

Out of 411,000 acres, only 12·4 per cent require reclamation. The detailed analyses of a typical profile are given in Table V.

TABLE V

Detailed analysis of Bist Doab tract profile

Depth	*p*H	Total salts Per cent	Calcium carbonate Per cent	Degree of alkalisation	Nitrogen humus in milligrams per 100 gm. of soil	
1 ft.	8·9	0·07	5·3	10·6	234·0	57·4
2 ft.	8·8	0·08	4·0	6·3	202·8	46·2
3 ft.	8·8	0·06	1·3	7·7	115·0	43·8
4 ft.	8·9	0·07	1·3	12·5	..	..
5 ft.	9·0	0·07	1·0	21·6	..	..
6 ft.	9·0	0·06	1·0	20·5	..	..
7 ft.	9·1	0·06	1·0	11·7	..	..
8 ft.	9·2	0·06	0·9	32·1	..	..
9 ft.	9·4	0·06	1·5	22·0	..	..
10 ft.	9·2	0·07	1·3	24·5	..	..

The above results show that the degree of alkalisation has exceeded the toxic limit (greater than 25 per cent) only in the 8th foot, otherwise the alkalinity even at lower depths is not very high. The major exchangeable base in most of the profile is calcium, which is a great contributory factor in keeping up the fertility index.

Eight water table profiles were exposed at different places. The results of variation in total salts and moisture content with depths in one of the typical profile are represented in Fig. 4.

Village—TIBBI
Tehsil—PHAGWARA
Block—B : D : 24
P—No. 2

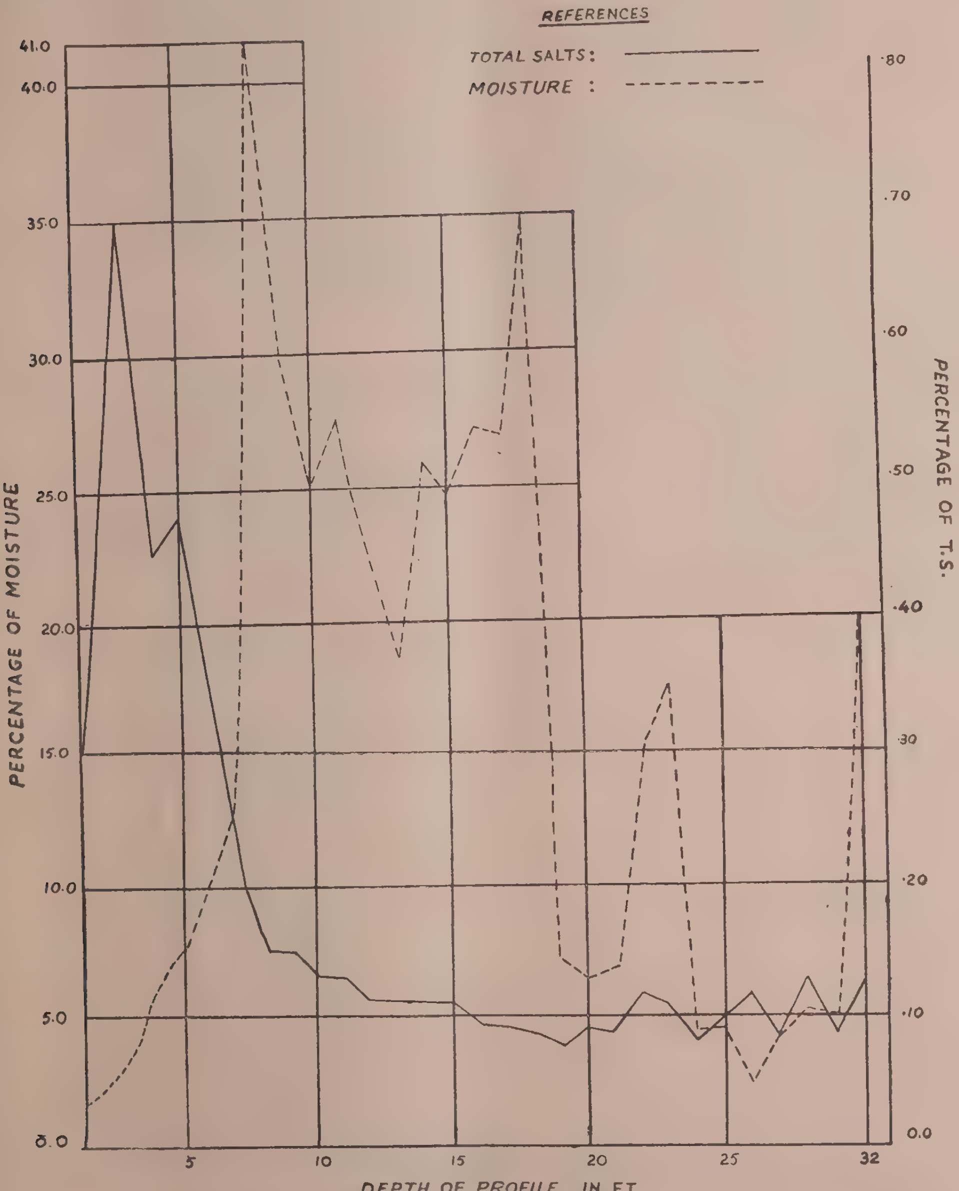

Fig. 4. Graph showing variations in total salts and moisture content with depth in Tubbi village.

The water table varies from 11 feet to 34 feet and the sub-soil water is fit for irrigation.

In deep profiles, where the salt zone occurs at different depths in zones of accumulation, there is every possibility of the rise of salts with the rise in water table. Scientific crop planning is to be carried out in such areas in order to mitigate the above effect.

Quality of irrigation water

Taylor, Puri, Asghar and Dhawan [1935, 1948] have specified the following limits for the quality of irrigation water.

Water containing total soluble salts less than 60 parts per 100,000 are suitable for irrigation

All waters having 60 to 120 parts of total solids per 100,000 are to be classified according to the following empirical equation

Salt Index=(Total Na-24,5)

—(Total Ca-Ca in $CaCO_3$)$\times$4·85)

The salt index is negative for all good waters and positive for those unsuitable for irrigation purposes.

Waters containing total solids more than 120 parts per 100,000 are unfit for irrigation purposes.

Water samples were taken from a number of wells situated in the different districts and analysed for their chemical constituents. Table VI shows the proportions of the suitable wells in the various districts.

TABLE VI

Name of the district	Percentage of	
	Good wells	Bad wells
Hissar	30·0	70·0
Karnal	38·0	62·0
Ludhiana	100·0	
Ferozepur	17·0	83·0
Jullundur	90·0	10·0

For comparison purposes the average results of wells of the districts mentioned above are given in Table VII.

TABLE VII

Proportions of chemical constituents in waters of different districts

(*Results expressed in parts per 100,000*)

Name of the salts	Average quantity in			
	Hissar	Karnal	Ferozepur	Jullundur
Calcium sulphate	..	..	..	4·65
Calcium carbonate	1·44	1·8	1·8	0·9
Calcium bicarbonate expressed as calcium carbonate	16·36	6·83	11·05	26·45
Calcium chloride	..	..	..	5·5
Sodium sulphate	18·22	11·5	24·5	14·7
Sodium carbonate	1·32	6·4	2·3	0·6
Sodium bicarbonate expressed as sodium carbonate	32·84	45·53	47·4	10·97
Sodium chloride	19·1	7·03	14·13	12·0
Total	89·2	79·06	101·2	75·5
pH	8·25	7·78	8·56	8·06
Salt Index	Positive	Positive	Positive	Positive

TABLE VIII

Classification of land surveyed in different tracts of Bhakra soil survey

Name of tract	Total area in this tract	Area surveyed as calculated from profiles	Land good in all respects		Area excessively sandy, salt content and pH values normal		Area having high salts with or without high pH at same depth of profile		Area having high pH value near the surface	
			Area	Per cent	Area	Per cent	Area	Per cent	Area	Per cent
Rori Chautala Tract	683346	555000	287400	51·78	61200	11·02	124200	22·37	82200	14·81
Rangoi Tohana Tract	395341	383400	205200	53·52	11400	2·97	72600	18·93	94200	24·56
South of Fatehabad & Sirsa Tract	375902	372600	201600	54·10	108000	28·98	45000	12·07	18000	4·83
Barwala Extension Tract	147576	192600	111000	57·63	38400	19·93	19200	9·91	24000	12·46
South-west of Hissar Tract	74803	72000	36600	50·83	21600	30·00	11400	15·83	2400	3·33
West of Pahow Tract	451518	482400	271800	56·43	1800	0·37	60200	14·55	138600	28·73
Khanna-Samrala Tract	168632	192600	165000	85·66	600	0·31	14400	7·47	12600	6·54
Ludhiana Jagraon Tract	Not known	175800	138000	78·49	13800	7·84	9600	5·46	14400	8·19
Grey Canal Tract	425000	466800	244800	52·44	32400	6·94	62400	13·36	127200	27·24
Bist Doab Tract	Not known	411000	349200	84·96	10800	2·62	32400	7·88	18600	4·52
TOTAL	..	3304200	2010600	60·85	300000	9·08	461400	13·96	532200	16·11

The sodium bicarbonate is the principal salt in the waters of Hissar, Karnal, and Ferozepore Districts which will slowly produce signs of deterioration [Asghar and Dhawan, 1948].

The future crop-planning has to take full consideration of this aspect of the question. Asghar and Dhawan [1948] concluded from their experiments that treatment of bad waters could be affected by the addition of gypsum or calcium permutite.

As a result of Bhakra Soil Survey we know that approximately 10 lacs acres of land need treatment before they can be put under normal rotation of crops. This Survey covered only six Districts of Hissar, Karnal, Ambala, Ludhiana, Ferozepur and Jullundur.

Summary

Approximately 61 per cent of land is fit for cultivation on the introduction of canal irrigation.

About 30 per cent are in different stages of deterioration and require treatment. High salt content exists at different depths even up to 120 ft. depth from the surface. In two Tehsils of Karnal 80 per cent of the land needs reclamation.

Nine per cent area is excessively sandy. Green manuring is recommended before putting such areas on normal cropping system. Canal irrigation will have to be controlled in these areas to avoid unnecessary wastage of water to excessive seepage.

The predominant salt in Karnal District is sodium carbonate or sodium bicarbonate, and in the other Districts it is sodium sulphate or sodium chloride.

Green manuring and application of farmyard manure are recommended for Ludhiana soils as they appear to have reached fatigue stage.

The maximum percentage of good well waters for irrigation is in Jullundur District and the minimum percentage is in Ferozepur District.

The principal salt in the waters of Karnal, Hissar and Ferozepur Districts is sodium bicarbonate, which will produce slow deterioration.

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DEVELOPMENT AND MORPHOLOGY OF VINDHYAN SOILS

I—CATENARY RELATIONSHIP EXISTING AMONG THE SOILS OF THE UPPER VINDHYAN PLATEAU IN UTTAR PRADESH

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THE site selected for studies reported in this paper forms the southernmost part of the Varanasi (previously Banaras) district comprising the whole of taluqa Naugarh, and a part of the great Vindhyan tableland lying between the Vindhyan escarpment and the Kaimur range. Covering an area of roughly 300 square miles of the district and lying between the parallels of 24°56′ and 25°04′ north latitudes and 83°13′ and 83°24′ east longitudes, the plateau is an extension of the Upper Kaimur sandstones as found in the Mirzapur district towards the west. Its northern face is approached from the plains through a series of slightly broken hills, the outiiers of the same formation as the tableland. Above the scarp, the country is covered with hills and jungles. The general direction of the hills is east to west and parallel with the face of the plateau, but there are numerous cross ranges in every direction specially in the east—south east. The hills are all rugged and none of them attains any great height. The plateau itself may stand at an average elevation of about 500 feet above the valley of the Ganges. The topography of the northern part being hilly is highly complex. The country is drained by two well-defined streams, the Chandraprabha and the Karamnasa, with their many small, shallow and at time dry affluents, all finding their way into the valley of the Ganges. The densest jungle, consisting of deciduous forest interspersed with some evergreen trees, is in the north of the plateau. Towards the south, the country becomes more open and the surface relief assumes the form of a gently undulating plateau intersected by low wooded ridges. The native vegetation has now got mixed with various type of grasses which serve as excellent grazing ground for cattle.

Climate. The climate of the district is sub-tropical monsoonic with an average annual rainfall of 43 inches. The wettest months are June to September recording about nine-tenth of the total precipitation. The average annual temperature is 78°F ; but in summer the absolute temperature often rises above 115°F and the

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N.B.—This paper is a contribution from the Regional Soil Laboratory, Banaras.

winter temperature may fall below 45°F. The average relative humidity for the year comes out to be 72 per cent. Lang's rain factor is 44 mm. per degree centigrade which puts the soils of the tract into the Red and Yellow Earths of the world soil-climatic regions, and the Meyer's N. S. quotient is 165 indicating a still drier type of soil formation.

Geology, parent material and age of the land. The soils are residual in origin having developed on the decomposition products of the sub-adjacent rocks of the Vindhyan system. The geological formations are a part of the Upper Kaimur sandstones belonging to the Kaimur series of the Upper Vindhyans and ranks amongst the oldest hill formations in the country. The sandstones are composed of massive rocks of uniform fine-grained texture and are arnaceous or mainly siliceous in character.

Field and Laboratory Methods

The technique adopted for the detailed field study of soils was essentially the same as that given for the reconnaissance soil mapping in the Soil Survey Manual [U.S.D.A. 1951] as adopted for the soil survey of the Varanasi district [Agarwal and Mehrotra, 1952]. Site selection for the examination of soil profiles was made on traverses at intervals of 4 miles each both vertically and horizontally. Three profiles were examined from each site so fixed, which represented the normal type and all possible significant soil variations as a result of topography, drainage and vegetative cover. The site characteristics and morphological features for each profile were recorded *in situ*.

Soil samples drawn from typical profiles were subjected to detailed laboratory examination. After air drying, the samples were sieved through 2 mm. round hole standard sieves and the portion passing through was employed for subsequent analyses. Mechanical analysis was done by the international pipette method of Robinson [1933]. Chemical composition was determined by fusion of the soil with alkali carbonate in the manner recommended by A.O.A.C. [1935] and analysing for the usual basic constituents as outlined by Piper [1950] for silicate analysis. Organic carbon was estimated by Walkley and Black's [1934] method and total nitrogen by a modified Kjeldahl's method given by Wright [1939]. Clay was separated by following the method of Robinson [Wright, 1939]. The fusion and analysis of clay were carried out in a manner described by Piper [1950]. Exchange capacity was determined by neutral normal ammonium acetate. Free iron oxide in clay was determined by treatment with hydrogen sulphide by the method given by Drosdoff and Truog [1935].

Soil description. The soils of the sub-mountainous tracts are shallow, coarse grained and red coloured. They are always underlaid by *murram* (ferrugenous gravels) and finally by parent bed rock. The soils of the valleys and lowlying flats are, however, deep and fine in texture. They are free from *murram* and rocks seldom appear at profile depths. No very well defined and separated soil regions can be found to occur because of the diversified pattern of relief, and the soils occur in catenary sequences

forming a well knit compound soil unit. Three broad natural divisions forming a major catena can, however, be possible on the tableland with some micro-catenary variations. They comprise the Vindhyan uplands in the north, Vindhyan lowlands in the south and Vindhyan flats occupying the vast flat and foot hills in the centre of the plateau. These divisions are mainly on the basis of topography, drainage and soil texture. Characteristic features of each division are described below :

(i) *Vindhyan uplands.* These soils occupy the high level sites and are basically eluvial in nature being formed under excessive drainage. Since water percolation is good, leached soils have developed. The soils are coarse grained, red and very shallow, the profile depth varying from 4 feet to 1 foot with even bare rock outcrops at places. Along the mountainous terrains erosion is very common and this washing away of the soil has brought about a number of depth-cum-textural soil phases. The vegetation varies from forest traces and shrubs on deeper soils to mere scrub jungle and perennial herbs on shallow beds and rock outcrops [Gupta, 1955]. The soils are poor in nutrient and cultivation is sparse.

(ii) *Vindhyan flats.* The soils on the flats have developed under less well drained conditions. The surface relief is only slightly undulating to gently rolling. Percolation is good but is slow enough to initiate a tendency for clay accumulation. This factor coupled with the presence of the underlying rocks, which often appear at 6 to 8 feet depth, partly slow down the drainage and create a semi-water-saturated condition in the subsoils. It is this factor which differentiates this complex from that of the uplands. Their soils contain more of finer grained material, the profiles are deeper and exhibit better moisture conditions than those of the uplands. The principal vegetation consists of *sal* (*Shorea robusta*), *kahu* (*Terminalia arjuna*), *Jamun* (*Jambu*), *Engenia Jambolana*, etc., mixed with other species of the upland flats. The staple crop of these tracts is paddy which is raised on embankments.

(iii) *Vindhyan lowlands.* These soils are associated with low level sites and are consequently alluvial in character. Effects due to soil erosion are absent and a variety of soils having typical characteristics of drainage impedence are commonly met with. Where alternate submergence and leaching is possible considerable loss of bases has taken place and clay has formed characteristic pans. In its extreme form of development such a formation gives rise to a highly leached orange red profile, strongly acidic in character and resembling in many respects the Vindhyan uplands and supporting its normal vegetation of deciduous trees. Where percolation is restricted and the moisture regime is affected by a high ground-water table, black clayey soils with lime concretions are formed. The natural vegetation consists of grasses such as *moonj* (*Saccharum munja*) and *khas* (*Vetiveria zizaniodies*) scattered with *palas* (*Bwtea frondosa*). These tracts constitute the most fertile portions of the district which extensively grow paddy.

Experimental results

(a) *Site characteristics and morphology.* During the course of soil survey, morphological features of a large number of profiles were closely examined on the Vindhyan plateau from which five typical profiles were selected, the data for which are presented

in this article. These profiles fully illustrate the entire soil development series in a catenary sequence on the plateau. In the series, one profile represents the normal type of soil formation on the Vindhyan uplands; two on the Vindhyan flats; and the rest two on the Vindhyan lowlands representing the extreme ends of the drainage scale. They have been termed as Vindhyan type 1 to 5 in the increasing order of development in the series. Morphological features are outlined in Table I.

TABLE I

Morphology of Vindhyan soils

Horizon	Depth in inches	Morphological features
		Vindhyan type 1
A	0-6	Light yellowish brown (10 YR 6/4, dry) to dark brown (7·5 YR 4/4, moist) sandy loam; gritty to touch; weakly granular; friable, moderately hard on drying; medium acidic; roots and small amounts of organic matter present
B	6-36	Dark red (2·5 YR 3/6, dry) to dusky red (10R 3/4, moist) clay loam; strong granular; compact and hard on drying; slightly acidic; no concretions
B_3	36-48	Red (2·5 YR 5/8, dry) to dark red (2·5 YR 3/6, moist) gritty clay loam; heavily disseminated with dark red *murram* concretions; hard and compact; neutral in reaction; rests on hard bed rock
		Vindhyan type 2
A	0-5	Yellowish brown (10 YR 5/6, dry) to brown (7·5 YR 4/4, moist) loam, mottled with gray and yellow; moderately strong coarse granular; slightly compact; medium acidic; organic matter and roots rusted with yellow stains
B	5-20	Yellowish red (5 YR 4/6, dry) to dark red (2·5 YR 3/6, moist) clay loam; moderately weak medium blocky; hard and compact; slightly acidic; mottled with gray; some iron nodules present
B_2	20-32	Reddish brown (5 YR 4/6, dry) to dark reddish brown (5 YR 3/4, moist) clayey soil; moderately strong medium blocky, in other respects similar to above
B_3C	32-56 56-62	Yellowish red (5 YR 5/6, dry) to dark reddish brown (2·5 YR 3/4, moist) gravelly clay imbedded with *murram*; the lower layer is mottled in colour due to massive iron redistribution; neutral; hard and compact; some iron nodules present; resting on the parent bed rock

TABLE I—*contd.*

Morphology of Vindhyan soils

Horizon	Depth in inches	Morphological features
		Vindhyan type 3
A	0-9	Yellowish gray to dark olive gray heavy loam; moderately strong blocky; compact; slightly acidic; organic matter and roots in plenty and rusted with iron stains; a few iron nodules but no lime concreations
B_2	9-21	Pale olive to olive clay loam of compact transition horizon specked with red and yellow colour
B_2	21-33 33-49 49-72	Grayish yellow clay loam; hard and indurated; strong blocky; faintly acidic to neutral in lower horizons; iron nodules more pronounced; wet and sticky at the bottom
		Vindhyan type 4
A	0-7	Light yellowish brown (2·5 Y 6/4, dry) to olive brown (2·5 Y 4/4, moist) clay loam, mottled with gray and yellow; compact; moderately strong coarse granular; strongly acidic; organic matter and roots; and some iron nodules present
B_{21}	7-19	Yellowish brown (10 YR 5/6, dry) to dark yellowish brown (10 YR 4/4, moist) clayey soil with variegated shades of gray and yellow; hard and compact; strong fine angular blocky; medium acidic; iron nodules more prominent
B_{22}	19-48	Reddish yellow (7·5 YR 6/6, dry) to yellowish red (5 YR 6/6, moist) clayey soil mottled with bright red and yellow; heavily compact, hard and indurated; very strong medium blocky structure; medium acidic; iron nodules many, horizon of maximum iron ielluviation
B_{23}	48-72	Brownish yellow (10 YR 6/6, dry) to brown (7·5 YR 4/4, moist) clay, in other respects similar to above but less mottled and slightly less acidic
		Vindhyan type 5
A	0-5	Olive gray (5 Y 5/2, dry) to very dark grayish brown (2·5 Y 3/2, moist) clay loam; moderately strong fine subangular blocky; sticky, compact; mildly alkaline; organic matter and roots rusted with iron stains; a few calcareous nodules present
BBca	5-25 25-41	Pale olive (5 Y 6/3, dry) to olive (5 Y 5/3, moist) clay loam, heavier than above and with some yellow spots; strong, medium angular blocky; hard and indurated; moderately alkaline small sized *kankar* in abundance; few iron nodules in the upper layer
BCsa	41-72	Same as above but little calcareous, strongly alkaline and sticky in nature

Vindhyan soil type 1 belonging to the uplands is a typical profile sampled from village Hinuatghat located on a hilly top and having an altitude of about 900 feet above sea level. The tropical heat and sub-humid climate under free drainage have affected a complete disintegration of the parent material and leaching of all soluble constituents. Extensive iron redistribution with the formation of ferrugenous gravels (*murram*) has occurred in the subsoil. Clay has been markedly eluviated to lower depths in the profile. Apart from depth phases, profile features vary within a very narrow range, because differences due to the drainage are not so marked as those due to erosion and colluvial movements. Only one profile occurring under upland relief typifying the combined effects of climate and other pedogenic factors has, therefore, been reported in the article.

Of the Vindhyan soil types 2 and 3 collected from the flats, the former was sampled from village Semra about two miles from the hills and developed under fairly good drainage. A typical profile shows a surface horizon of yellowish brown to brown soil and shows presence of organic matter and adequate amounts of clay with medium acid reaction. It is underlaid by a fairly deep layer of reddish yellow mottled clay. Acidity decreases with depth and the lower most horizons are impregnated with *murram* which finally rest on semi-decomposed rock. Type 3 soil is from a slowly drained landscape selected in village Naugarh whose site was away from the hills. Restricted drainage and higher water table has brought about greater intrazonal characters and the corresponding profile has in comparison greater depth with finer texture and more saturated with bases, showing characters intergrading with those of the lowlands.

Vindhyan soil types 4 and 5 are associated with lowlands. Soil type 4 was sampled from village Bhaisaura far away from the hills and developed under lowlying relief which gets submerged in rains. Internally the soil is fairly drained and the leaching of the bases is more effective. The characteristic profile thus possesses, at the surface, a compact thin layer of grayish yellow to olive brown clay loam and strongly acid soil accompanied by a very deep B horizon of highly compact clay soil. These can be differentiated into subhorizons on the basis of the occurrence of an abundance of sharp red and yellow orange mottlings and eluviation of iron and manganese compounds and their subsequent precipitation. Soil type 5 exhibits the extreme end of the drainage scale on the Vindhyan plateau and was sampled from village Bojh located on the southern border of the district. Water table was high and the drainage extremely restricted. The typical profile shows a dark thin surface layer, rich in organic matter and sharply differentiated from the underlying deep horizon of calcareous clay soil imbedded throughout with *kankar* nodules. Stains of ferrous iron are visible at many places with gleii appearance. The good reserves of lime and organic matter appear to preserve the tilth of these soils ; otherwise, they are highly sticky and get puddled when wet and hard when dry breaking into large lumps. The soils are known to possess high moisture retentive capacity and can yield fairly good crops without much supplemental irrigation.

(b) *Mechanical and chemical composition.* Table II contains the mechanical composition of the five types of Vindhyan soils. The data correspond very closely to field observations. The eluvial nature of the upland soil is reflected in the coarse

grained nature of the A horizon of type 1 soils. At the bottom horizons of type 1 and type 2 soils, *murram* gravels formed the bulk of the original soil. The fine earth in them is equally clayey indicating the pronounced eluviation of clay from upper horizons. In soils of the lowlands, the proportion of sand fraction decreases and the composition is balanced by the more finer particles of clay.

TABLE II

Mechanical composition of Vindhyan soils

(Per cent oven-dry soil below 2 mm.)

Horizon	Depth in inches	Coarse sand	Fine sand	Silt	Clay
			Vindhyan type 1		
A	0-6	19·01	50·52	16·16	12·87
B_2	6-36	7·93	34·06	19·40	38·01
B_3	36-48	13·28	29·80	18·13	38·84
			Vindhyan type 2		
A	0-5	6·02	52·71	24·45	17·58
B_1	5-20	5·20	37·95	23·74	33·24
B_2	20-32	4·24	28·27	21·59	45·98
B_3C	32-56	9·29	29·09	20·89	40·83
			Vindhyan type 3		
A	0-9	3·45	50·69	22·34	22·60
B_2	9-21	4·92	47·56	20·50	27·98
B_3	21-33	6·20	37·23	19·41	36·42
	33-49	1·93	39·61	20·29	37·56
	49-72	1·50	40·52	21·84	35·48
			Vindhyan type 4		
A	0-7	2·70	41·78	28·98	25·93
B_{21}	7-19	3·39	29·07	21·40	46·40
B_{22}	19-48	3·09	29·49	20·91	46·22
B_{23}	48-72	3·17	29·52	22·75	45·50
			Vindhyan type 5		
A	0-5	4·22	45·80	22·02	26·11
Bca	5-25	4·10	26·19	24·80	37·73
	25-41	3·29	31·59	24·04	36·45
BC Sa	41-72	3·20	37·16	22·14	36·04

TABLE III

Chemical composition of Vindhyan soils

(Per cent oven-dry soil below 2 mm.)

Depth in inches	SiO_2	R_2O_3	Al_2O_3	Fe_2O_3	TiO_2	P_2O_5	CaO	MgO	K_2O	MnO	CO_2	Loss on ignition
Vindhyan type 1												
0-6	87·90	10·10	6·90	2·88	0·31	0·057	0·57	0·40	1·05	0·047	nil	1·02
6-36	76·14	18·35	12·86	5·10	0·35	0·045	0·63	0·79	1·56	0·069	nil	3·73
36-48	71·29	22·01	15·08	6·55	0·35	0·045	0·65	0·83	1·61	0·087	nil	4·12
Vindhyan type 2												
0-5	80·81	13·91	10·24	2·94	0·65	0·076	0·57	0·51	1·41	0·058	nil	2·40
5-20	72·87	20·23	14·30	5·12	0·71	0·103	0·72	0·75	1·58	0·058	nil	3·79
20-32	65·07	26·39	18·46	7·19	0·71	0·065	0·81	1·18	1·83	0·091	nil	4·82
32-56	62·69	28·32	18·43	9·15	0·68	0·064	0·58	1·01	1·76	0·061	nil	5·05
Vindhyan type 3												
0-9	78·29	15·17	9·90	4·44	0·72	0·110	0·71	1·09	1·73	0·048	nil	4·22
9-21	77·57	16·44	10·92	4·85	0·59	0·079	0·78	1·09	1·72	0·030	nil	3·64
21-33	70·68	21·51	14·48	6·30	0·64	0·086	0·78	1·35	2·00	0·104	nil	4·73
33-49	67·53	23·44	17·19	6·52	0·65	0·079	0·93	1·55	2·01	0·101	nil	5·20
49-72	67·35	23·20	16·18	6·31	0·63	0·079	1·00	1·72	2·01	0·100	0·25	4·93

TABLE III—*contd.*

Chemical composition of Vindhyan soils

(Per cent oven-dry soil below 2 mm.)

Depth in inches	SiO_2	R_2O_3	Al_2O_3	Fe_2O_3	TiO_2	P_2O_5	CaO	MgO	K_2O	MnO	CO_2	Loss on ignition
Vindhyan type 4												
0- 7	77·85	15·76	11·14	3·87	0·65	0·103	0·31	0·64	1·59	0·066	nil	3·97
7-19	69·00	23·85	17·02	6·09	0·64	0·117	0·36	0·83	2·25	0·085	nil	5·36
19-48	66·28	25·39	17·71	6·92	0·64	0·113	0·38	1·01	1·87	0·099	nil	5·64
48-72	66·80	25·04	17·76	6·51	0·65	0·145	0·55	0·96	1·85	0·095	nil	5·17
Vindhyan type 5												
0- 5	74·99	16·65	11·70	4·20	0·66	0·089	1·90	1·15	1·12	0·086	0·92	4·00
5-25	64·80	20·43	14·48	5·27	0·60	0·070	4·98	1·49	1·47	0·075	3·34	3·98
25-41	67·36	20·70	15·70	4·45	0·50	0·064	2·77	1·57	1·30	0·064	1·65	4·18
41-72	70·73	20·10	15·59	4·02	0·43	0·064	2·08	1·65	1·30	0·097	1·13	3·21

The data on chemical composition, given in Table III, are, in general, agreement with the mechanical composition and drainage conditions. Type 1 soils are thoroughly depleted of their alkalies and alkaline earth bases with consequent enrichment in silica. Translocation of iron and alumina is quite pronounced. Bases to alumina and calcium to magnesium ratios decrease in the profile indicating faster leaching of the bases out of the *solum* and an advanced stage of soil development as shown in Table IV. The soils are poor in nutrients and organic matter. Deficiency of lime and soluble salts has introduced a slightly acidic character to these soils which become neutral in the zone of *murram* formation.

TABLE IV

General analyses

Depth in inches	Organic carbon	Total nitrogen	Organic matter	C/N	pH	*Bases / Al_2O_3	CaO† / MgO	Al_2O_3† / Fe_2O_3
				Vindhyan type 1				
0-6	0·54	0·052	0·93	10·5	6·1	0·463	1·02	3·76
6-36	0·31	0·042	0·53	7·3	6·0	0·379	0·58	3·95
36-48	0·44	0·050	0·76	8·8	6·9	0·335	0·56	3·62
				Vindhyan type 2				
0-5	1·01	0·088	1·74	11·5	5·8	0·378	0·80	5·46
5-20	0·48	0·057	0·83	8·5	6·1	0·347	0·68	4·38
20-32	0·26	0·037	0·45	7·1	6·4	0·345	0·49	4·03
32-56	0·24	0·036	0·41	6·6	6·6	0·300	0·42	3·16
				Vindhyan type 3				
0-9	0·97	0·091	1·67	10·7	6·4	0·591	0·47	3·50
9-21	0·22	0·030	0·38	7·3	6·4	0·555	0·51	3·54
21-33	0·21	0·030	0·36	7·0	6·6	0·486	0·41	3·60
33-49	0·15	0·025	0·26	6·0	6·7	0·465	0·43	4·14
49-72	0·14	0·023	0·24	6·1	7·0	0·518	0·42	4·02

TABLE IV—*contd.*

General analyses

Depth in inches	Organic carbon	Total nitrogen	Organic matter	C/N	pH	*Bases / Al_2O_3	CaO† / MgO	Al_2O_3† / Fe_2O_3
Vindhyan type 4								
0-7	0·85	0·078	1·46	10·8	4·9	0·352	0·34	4·52
7-19	0·32	0·043	0·55	7·4	5·6	0·304	0·32	4·39
19-48	0·19	0·030	0·40	6·3	5·8	0·300	0·27	4·01
48-72	0·18	0·030	0·30	6·0	6·0	0·308	0·41	4·28
Vindhyan type 5								
0-5	1·38	0·126	2·37	10·7	7·5	0·648	1·18	4·37
5-25	0·21	0·042	0·36	5·0	8·1	1·002	2·39	4·31
25-41	0·18	0·035	0·30	5·1	8·3	0·665	1·26	5·54
41-72	0·14	0·025	0·24	5·6	8·7	0·596	0·90	6·09

*$CaO+MgO+K_2O$ †indicate molar ratios.

The distinguishing features in the chemical composition of types 2 and 3 soils lie in the higher values of their acid soluble constituents. Due to greater moisture and humus in the soil, the mobility of iron is comparatively more than that of alumina. The differences in between the two types arise out of their differences in drainage. Type 2 soils shows greater leaching and an approach to type 1 in zonation. Type 3 soils in the same series is the intrazonal counterpart and is better supplied with the basic nutrients and other bases.

The chemical composition of type 4 and 5 soils shows their greater sesquioxidic nature as a result of the widening effect of the drainage scale. Type 4 soils are highly leached of their bases and have developed strongly acidic characters. The bases to alumina and calcium to magnesium ratios have decreased still further although potash and magnesia which are less susceptible to leaching tend to accumulate at the cost of lime. In type 5 soils, on the other hand, all the products of weathering including some soluble salts accumulate. The soils are, therefore, richly calcareous and get strongly alkaline in the subsoils.

(c) *Composition of clay separates.* In Table V are listed the data of chemical composition of the clay fractions of the five types of soils of the Vindhyan catena. The derived molecular ratios are given in the subsequent table. The data indicate that the clays from the excessively drained type 1 soils are rich in sesquioxides showing slight eluviation, both in respect of iron and alumina. The contents of bases are low and decrease sharply in the ferruginous concretionary layer. Considerable amount of iron has gone out of the clay complex and accumulated in the

free state in the eluviated horizon. The eluviation of sesquioxides is reflected in the various molecular ratios which slightly decrease in the subsoil. The base exchange capacity is very low.

TABLE V

Composition of clay fraction of Vindhyan soils

(Per cent oven-dry-basis)

Depth in inches	SiO_2	Sesqui-oxides	Al_2O_3	Fe_2O_3	TiO_2	K_2O	MgO	Loss on ignition	Free Fe_2O_3
Vindhyan type 1									
9-6	41·88	41·32	29·36	11·14	0·82	1·74	1·10	14·14	6·20
6-36	42·11	45·00	31·64	12·59	0·77	1·52	0·89	10·95	7·69
36-48	42·15	45·63	32·15	12·68	0·81	1·32	0·69	10·73	7·04
Vindhyan type 2									
0-6	43·78	40·22	28·24	11·04	0·93	1·79	1·29	10·71	5·46
6-17	42·83	43·27	30·80	11·62	0·85	1·55	0·92	10·03	5·55
17-30	43·05	44·03	31·27	11·90	0·86	1·65	0·67	10·31	6·89
30-58	42·46	44·40	31·72	11·88	0·81	1·54	0·51	10·07	6·55
58-72	42·49	44·24	31·58	11·84	0·82	1·62	0·62	10·72	6·45
Vindhyan type 3									
0-5	46·82	39·41	28·26	10·21	0·94	2·11	1·41	11·48	4·77
5-21	46·24	42·13	30·00	11·14	0·97	1·95	1·47	9·56	4·79
21-33	45·36	41·34	29·42	11·02	0·91	2·27	1·64	9·65	4·18
33-49	47·45	40·63	29·10	10·65	0·88	2·20	1·62	9·22	3·94
49-72	47·65	40·46	29·62	10·02	0·81	2·19	1·88	9·29	3·77
Vindhyan type 4									
0-6	45·46	40·77	31·21	8·72	0·85	2·02	1·49	12·16	4·80
6-20	44·18	40·81	29·96	10·05	0·81	1·82	1·37	10·70	4·69
20-45	46·16	42·33	31·02	10·52	0·79	1·98	1·46	10·40	5·31
45-72	46·30	42·35	31·34	10·32	0·69	1·83	1·53	9·79	4·68
Vindhyan type 5									
0-5	47·13	37·94	27·08	10·17	0·69	1·99	1·85	11·54	2·88
5-25	48·47	38·02	26·69	10·59	0·75	1·77	2·09	10·12	3·07
25-41	50·94	36·95	25·66	10·38	0·92	2·20	2·30	9·09	3·03
41-72	48·50	39·33	28·30	10·23	0·80	1·93	1·92	9·38	3·79

TABLE VI

Derived molecular ratios of the clay fraction of Vindhyan soils

Depth in inches	$\frac{SiO_2}{R_2O_3}$	$\frac{SiO_2}{Al_2O_3}$	$\frac{SiO_2}{Fe_2O_3}$	$\frac{Al_2O_3}{Fe_2O_3}$	$\frac{SiO_2}{K_2O+MgO}$	Base exchange capacity m.e. per cent
			Vindhyan type 1			
0-6	1·95	2·43	10·01	4·13	15·12	27·3
636	1·81	2·27	8·92	3·95	18·24	22·0
36-48	1·78	2·23	8·86	3·98	22·32	24·3
			Vindhyan type 2			
0-6	2·11	2·64	10·58	4·01	14·22	31·7
6-17	1·91	2·36	9·83	4·16	18·07	24·5
17-30	1·88	2·34	9·64	4·12	20·91	25·6
30-58	1·84	2·28	9·52	4·19	24·32	27·6
58-72	1·85	2·29	9·57	4·18	21·66	28·0
			Vindhyan type 3			
0-5	2·29	2·82	12·23	4·34	13·52	41·8
5-21	2·12	2·62	11·07	4·23	13·39	34·7
21-23	2·12	2·62	10·97	4·19	11·61	34·6
33-49	2·25	2·77	11·87	4·27	12·37	35·6
49-72	2·25	2·74	12·69	4·64	11·31	40·7
			Vindhyan type 4			
0-6	2·10	2·48	13·90	5·61	12·90	33·6
6-20	2·07	2·51	11·72	4·68	14·00	27·2
20-45	2·08	2·53	11·69	4·62	13·37	36·1
45-72	2·08	2·51	11·95	4·76	13·37	26·3
			Vindhyan type 5			
0-5	2·39	2·96	12·38	4·18	11·65	52·9
5-25	2·47	3·09	12·21	3·95	11·33	46·0
25-41	2·68	3·38	13·09	3·88	10·49	49·0
41-72	2·37	2·91	12·63	4·34	11·79	44·2

The clay of Vindhyan type 2 is slightly more siliceous than that from type 1 soils. In presence of organic matter and better moisture conditions in these soils, movement of iron is more displayed than that of alumina. Exchange capacity has slightly increased. The contents of free iron oxide have diminished and the clay is better supplied with bases. Silica sesquioxide and silica-alumina ratios indicate some eluviation of sesquioxides and incipient podsolised nature similar to type 1 soils. Vindhyan type 3 soils which have developed on flats but under defective drainage are considerably more siliceous than their zonal associates. An enrichment with bases and a consequent diminution in profile differentiation is noticeable.

The chemical composition of clay fraction of Vindhyan type 4 soils presents a greater uniformity of distribution of various constituents, the only exception being that of iron which shows greater mobility due to submergence accompanied by leaching in the profile. The silica contents are roughly uniform at 46 per cent and so is the case with alumina at 31 per cent in the profile. Magnesia and potash seem to be less subjected to weathering than in the better drained soils of the flats and uplands. Silica-sesquioxide and silica-alumina ratios are fairly constant at 2·1 and 2·5 respectively. Exchange capacity is roughly the same as in type 3 soils.

The extreme end of the drainage scale is represented by type 5 soil which shows marked divergence in its clay composition. The clay is of a dark grey colour, significantly siliceous in nature and highly reactive both in its physical and chemical properties. Silica-sesquioxide and silica-alumina ratios slightly increase in the subsoil from a value of 2·4 and 3·0 to 2·7 and 3·4 respectively. Some silica translocation is visible while reverse is the case with sesquioxides. Of the latter, only alumina has slightly accumulated in the A horizon. The clay is rich in bases and low in contents of free iron oxide. The base exchange capacity is high, being of the order of 45 to 55 m.e. per cent.

Discussion

A comparative study of the morphological and other chemical characteristics of the entire soil development series on the Vindhyan plateau reveals certain well-defined relationships, explained from the features of the component types and their catenary positions. Descending the topographical sequence, we may notice the change of soil colour with drainage impedence from deep red in well aerated uplands through orange, yellow, olive and finally to dark grey with glei symptoms in the extremely poorly drained members. The texture also becomes finer in that order. From the mechanical composition a significant point of interest to note is that the individual fractions observe a certain regularity of variation with depth, as one moves from the uplands to lowlands; there is a greater diminution of profile differentiation on going down the drainage scale. The uplands are the most eluviated in their clay and fine materials but this tendency becomes less prominent on flats and is diminished to minimum in the poorly drained lowlands. The greater the degree of eluviation, the coarser is the resultant eluvial soil.

The catenary relationship among the soils of the Vindhyan plateau finds further support from the data of chemical composition which shows greater sesquioxidic character of the lowlands in comparison to flats and more so to uplands which are most siliceous in nature. The marked eluviation which is noticeable in almost all the mobile chemical constituents of the soils found on the uplands is lessened on the flats and diminishes still further in low-land soils. The various constituents also occur in the profile in the expected order of their mobility. The translocation of alumina keeps pace with iron in the well-drained soils of the uplands but lags behind on the flats and low-lands. In poorly drained soils of the latter category, translocation of iron is restricted and is manifested as precipitated iron in the form of nodules. Two other ratios as shown in Table IV call for notice. *viz*, the bases to alumina and calcium to magnesium ratios indicating the leaching of bases with respect to alumina and the preferential leaching of calcium over magnesium. The two ratios almost together follow different courses in the hydrologic sequence across the topographical catena. Thus in soil types 1, 2 and 4, the ratios ; et narrower, while in types 1, 3 and 5, they widen up in that order. In one direction, the soil pH decreases across the topographical sequence, while in the other, it moves towards the alkaline side. A similar increase in acidity has been reported in the soils of Kenya Colony by Gethin Jones [1949] in which the base of the series is more acidic than the uplands. The data on carbon-nitrogen ratios bring out a similar striking relationship in the soil sequence. As the drainage becomes impeded, the transition to subsoil becomes sharper and the carbon-nitrogen ratios narrower. The data on the composition of clay fraction confirm the existence of such relationship. The silica : sesquioxide and silica : alumina ratios of type 4 soils show affinity to type 2 and type 1 soils developed under fair to rapidly drained relief, while similar ratios of type 3 soils approach those of type 5 soils characterised by poor drainage. Silica : iron oxide and alumina : iron oxide ratios on the other hand show a modified trend due to the greater mobility of ferrous iron in the humid lowlands. Alumina eluviation keeps pace with iron in type 1 to type 3 soils, becoming less in that order, but vanishes in type 4 and is reversed in type 5 soils. In the latter case when the ground water level begins to affect the profile development, lateral movement of iron interferes with its vertical leaching. Another significant fact to be noticed is the greater enrichment at the lower end of the catena with bases in its clay composition and the increase in its exchange capacity. The decreasing contents of free iron oxide similarly indicates greater weathering and break down of the clay complex on the uplands in comparison to low-lands.

The above interpretation is fundamentally different from the conception that the black soils are the transported red soils of the uplands subsequently converted black in the lowlands as has been suggested by a number of workers [Sen, 1939; Raychaudhuri, 1941]. The black *mar* soils of Bundelkhand reported by the senior author in another paper [Agarwal and Mukerji, 1946] seem to be similarly related with the upland red soils occurring in close proximity to each other. The bulk of the data in hand, however, deny the existence of such a possibility in Vindhyan soils. For, there are significant differences between the highly leached red soils and the poorly drained black clays. The clay fractions of red soils have got low

silica : sesquioxide and silica : alumina ratios, are low in bases and cation exchange capacity. The significantly higher contents of free iron oxide in them indicate their highly weathered character and the higher state of oxidation of iron imparts a typical red colour to these soils. The black clays, on the other hand, have got higher silica : sesquioxide and silica : alumina ratios, are rich in bases and possess an exchange capacity which is double that of red clays. They are associated with active physical properties, high plasticity and power of expansion and contraction. These properties suggest that the black clays contain montmorillonite and illite as basic minerals, whereas the red ones mainly kaolinites and halloysites with admixture of possibly gotnite and limonite. The data reported by Raychaudhuri *et al.* [1943] for the red and black soils of Coimbatore in South India support the conclusions arrived at above. It is doubtful whether the highly resistant minerals of the former group would ever undergo simplification to form the bulk minerals of the latter. The formation of different types of red and black soils would evidently depend largely upon the conditions of drainage, and the amount and nature of other ions present, notably the alkalies and alkaline earth-bases.

It may be observed that the eluvial soils of the Vindhyan plateau are shallow red coloured and underlaid by a densely packed horizon of ferruginous concretions overlying the parent sandstone rock. Such concretions commonly pisolitic in nature are called *murram* and have been found to occur in the subsoil only unless exposed to the surface by erosion. Beyond the occurrence of these lateritic concretions and the development of bright red colour, there is little characteristic of the true laterites in these soils. The desilicification has not advanced to an extent to lower the silica : sesquioxide ratio of the clay fraction appreciably below 2·0. The silica : sesquioxide ratios of the clay of maximal zonal soils are slightly below 2·0, but it may vary from 2·2 to 2·4. Evidently these soils contain significant proportions of alumina-silicate minerals in their clay fractions. The figures of molecular ratios are such that might be expected for the typical brown earths or the younger red loams of tropical climates. The body of the data for the chemical composition of the total soils lend support to this conclusion. Reifenburg [1940] has examined the data of clay composition of the great soil groups which are given below for tropical soils :

Soil type	SiO_2/Fe_2O_3	SiO_2/Al_2O_3	SiO_2/R_2O_3
Mediterranean red soils	9·3	3·3	2·4
Brown earths	9·4	2·4	2·0
Subtropical and tropical red soils	8·2	2·3	1·6
Laterites	8·5	1·7	1·3

The silica-sesquioxide and silica-alumina ratios of clay fraction for our soils are lower than that of brown earths but are slightly higher than that for red soils. In view of greater degree of weathering and the development of tropical red colour with abundance of ferruginous concretions in the profile, these soils show greater affinity to tropical red loams with which they can be associated in any scheme of soil classification. A critical perusal of the chemical data would reveal a certain

amount of eluviation of sesquioxides in the profile. This is not equally reflected on the enrichment of the upper layers with silica indicating that the latter is also subjected to leaching processes along with bases. The other chief pedogenic processes responsible for the formation of these soils consist of the excessive mechanical eluviation, the consequent bleached colour of the surface horizon and the formation of iron-stone concretions in the subsoil all of which would favour a type of soil formation only known under the tropical conditions. In the dynamics of our soil formation, therefore, we notice both the affinities for lateritic and other intermediatory soil processes, a feature that must be regarded as indicative of some transitional type of tropical soils. Further, in view of what has been observed above, the Vindhyan soils show another stage of degradation from brown earths towards laterisation, the degradation being the result of long periods of intensive weathering followed by leaching resulting in partial desaturation under the prevailing sub-tropical climate.

Summary

A pedo-chemical study has been made on the soils of Vindhyan plateau belonging to Varanasi district in Uttar Pradesh. The soils have been grouped under three broad topographical divisions forming the Vindhyan uplands, Vindhyan flats and Vindhyan lowlands. Detailed morphological characteristics and data on mechanical and chemical composition of five genetic soil types have been presented to bring out the soil development and the catenary relationship existing among the soils of the Vindhyan plateau. This sequence in relationship has also been studied in the clay separates isolated from different soil types. The linked nature of the soils has been elucidated and the meaning and the scope of the terms employed for the broad soil divisions have been discussed. The pedogenic associationship between red and black soils has also been discussed. An insight into the nature of soil formation has been obtained from the data and it has been pointed out that the process is similar to one that gives rise to tropical and sub-tropical red loams.

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SOIL CONDITIONS FOR THE GROWTH OF SAFFRON AT PAMPORE (KASHMIR)

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PAMPORE is a place in Kashmir where saffron grows in plenty. It is situated about eight miles from Srinagar the capital of the State. In a stretch of land at Pampore good saffron is being grown year after year whereas in its vicinity there are areas where no crop grows to the benefit of the cultivators although the elevation (5,200 ft.) and rainfall (25 inches per annum) of both the areas are identical. The object of the present investigation was to find out the differences in the physical and chemical properties of the two types of soils and to assess the soil conditions suitable for the healthy growth of saffron.

Material and Methods

Profile samples of the two adjacent lands, field I and field II, the former capable of growing good saffron and the latter where saffron does not grow, were collected in 1953. Four average samples at known depths were collected in each profile, the depth being decided by morphological features of the profiles.

Mechanical analysis of the soils was carried out by the International method as modified by Robinson [1933]. The major nutrients were estimated by piper's methods [1947]. The available P_2O_5 was estimated by Olsen's method [1953] and the cation exchange capacity of the soils was determined by Schollenberger's method [1930]. Cobalt was estimated by Nitroso-R salt method [1944], manganese by periodate method [Willard and Greathouse, 1917] and copper and zinc by Holme's method [1945].

Results

The morphological descriptions of the two profiles and the other physical properties determined are given in Table I.

In field I where saffron is being grown for years, there seems to be a downward leaching with accumulation of $CaCO_3$ in the fourth layer (36-42th) whereas field II is characterised by high content of $CaCO_3$ throughout the profile possibly due to free surface drainage.

The chemical composition of the two profiles along with their cation exchange capacity, pH, organic carbon content and C/N ratio is given in Table II.

TABLE I

Morphological descriptions and physical properties of soils of two profiles collected from fields I and II

Field No.	Location, elevation, etc.	Lab. No.	Depth in inches	Morphological features	Mechanical constituents (per cent)						
					Gravel	Moisture	Loss on ignition	$CaCO_3$	Sand	Silt	Clay
I.	Location—Pampore, Srinagar	990/53	0—9	Moist, loose and structureless, dark brown soil, plenty of roots of grasses and some corns of saffron flowers.	0·8	2·42	0·89	0·70	33·94	43·12	20·28
	Elevation—5,200 feet	991/53	9—15	do. more compact .	1·4	2·86	0·54	0·61	32·00	40·36	23·40
	Rainfall—25 inches	992/53	15—36	Compact, concretionary layer showing iron, manganese concretions, shining mica type material in the concretions against the seam	..	3·73	2·14	1·83	24·72	33·45	32·40
	Soil growing good saffron Field fallow, but corn of saffron grows, the field was under cultivation of saffron for several years but now taken over by Government Grinding Mill	993/53	36—42	More clayey, light dark brown soil, less compact than the third layer	..	2·82	0·68	14·05	21·33	34·68	25·40
II.	Land not good for saffron	994/53	0—9	Light brown loam, structureless, plenty of plant roots	..	2·22	1·43	14·07	24·44	34·20	22·55
	Elevation—5,200 feet	995/53	9—20	do. more compact, some seeming calcareous nodules	..	2·24	2·74	13·87	20·25	35·55	25·10
	Rainfall—25 inches	996/53	20—36	do. more compact than 2nd layer and more calcareous than above	..	2·15	1·21	16·96	19·82	33·90	23·60
	Free drainage	997/53	36—48	Hard compact calcareous zone mixed with light brown soil	2·5	1·84	2·20	21·76	19·05	31·10	22·25

TABLE II

The chemical composition of the soils of the two profiles collected from fields I and II together with their cation exchange capacity, pH, organic carbon content and C/N ratio

Field No.	Lab. No.	Depth in inches	pH	Nitrogen p.c. (oven dry)	Organic carbon p.c.	C/N ratio	Cat. exch. cap. m.e. per 100 gm. soil	HCl soluble nutrients p.c. (oven dry)				Available nutrient p.c. (oven dry)	
								Fe_2O_3	CaO	MgO	P_2O_5	P_2O_5	K_2O
1	990/53	0—9	7·55	0·086	0·34	4·0	9·92	4·167	0·3951	0·1246	0·1059	0·096	0·0338
	991/53	9—15	7·7	0·071	0·31	4·4	16·76	4·073	0·2945	0·1278	0·1007	0·038	0·0319
	992/53	15—36	7·55	0·054	0·25	4·6	17·68	5·363	0·4478	0·1346	0·1315	0·040	0·0290
	993/53	36—48	8·21	0·050	0·31	6·2	13·20	4·749	7·567	0·2208	0·1562	0·075	0·0278
2	994/53	0—9	8·15	0·089	0·33	3·7	7·12	3·409	6·557	0·2209	0·1549	0·033	0·0214
	995/53	9—20	8·25	0·050	0·22	4·4	7·12	4·401	7·749	0·2292	0·1357	0·004	0·0266
	996/53	20—36	8·22	0·031	..	..	7·34	5·635	8·237	0·2263	0·1451	0·005	0·0194
	997/53	36—48	8·30	0·038	..	..	7·16	4·905	9·90	0·3412	..	0·009	0·0143

TABLE III

Micro-element contents of the soil samples of the two profiles collected from fields I and II

Field No.	Lab. No.	Depth in inches	Manganese p.p.m. D.M.					Cobalt p.p.m. D.M.	Copper p.p.m. D.M.	Zinc p.p.m. D.M.
			Water soluble	Exchangeable	Easily reducible	Active	Total			
1	990/53	0—9	0·51	12·55	97·9	110·96	891·5	11·3	20·3	13·3
	991/53	9—15	0·46	13·07	90·8	104·33	952·2	15·5	29·2	20·6
	992/53	15—36	0·26	5·97	73·7	79·93	1127·0	13·6	22·2	35·8
	993/53	36—48	0·41	3·09	111·1	114·60	671·9	12·1	12·2	31·9
2	994/53	0—9	0·36	4·86	72·1	77·32	751·7	13·0	13·7	32·7
	995/53	9—20	0·41	5·68	100·2	106·29	746·7	12·9	17·2	21·5
	996/53	20—36	*Nil*	3·32	96·1	99·42	710·2	13·1	12·1	24·0
	997/53	36—48	0·41	1·53	82·5	84·44	529·8	10·6	14·0	29·5

Accounting for the presence of $CaCO_3$ in the soil samples, the available P_2O_5 content estimated in field I is much higher than in field II. Available K_2O content also shows a similar trend. The micro-element status of the profiles studied is given in Table III.

Active Mn and copper seem to be high in the top layers of profile I as compared to the similar layers of profile II. Zinc, on the other hand, was found to be more in the top layer of profile II than in that of profile I a layer which forms the root zone of the saffron plants.

Discussion

The results recorded above bring out prominent differences in the two profiles as far as their calcium carbonate content is concerned. The high $CaCO_3$ content in Field II may be responsible for lower values of available P_2O_5 recorded. This may partly be attributed to the differences in the drainage conditions of the two profiles which is also reflected in comparatively larger values of sand content upto a depth of 15ft. in profile I as compared to profile II. Even though the percentage clay in both the profiles remains nearly the same, the higher values of cationic exchange capacity in profile I may perhaps be due to difference in clay minerals as the organic carbon content is nearly of the same order. Even though the organic carbon content and C/N ratios are not balanced as they should be in fertile soils, these do not seem to play any prominent role in the growth of saffron.

Regarding micro-elements, though no definite conclusions can be arrived at, it is possible that the availability of these elements may be restricted under high calcareous conditions of the soils in profile II with a higher *p*H value as compared to the soils in field I.

It is, however, necessary to examine from a large number of samples, how far the effect of calicum carbonate indicated in this investigation will be a limiting factor for the successful growth of saffron. Analysis of saffron flowers and bulbs may, also throw some light on this problem of fundamental economic importance to the Kashmir State.

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STUDIES ON TILLAGE

IV—EFFECT OF FREQUENCY OF CULTIVATION WITH AND WITHOUT PLACEMENT OF FERTILIZERS ON THE YIELD OF MAIZE

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NEXT to rice, millets, and wheat, maize is considered to be a major source of food for a large population of this country. It has a wide adaptability and is grown under varied range of climate and soil all over India. Its annual production from over 9 million acres of land is about 2·9 metric tons. These low yields from one of the most prolific of crops, which can produce about twice the yields of wheat from one-fifth quantity of seed and at less cost per maund, are probably because the crop has failed to catch the eye of the farmer and scientist alike in this country.

The yield of crop plant is governed by the genetic potentiality of the plant itself—which hasn't in our case undergone so much change as in other countries and the environments. The tillers of the soil still follow the same time-honoured practices as were adopted by their ancestors. The traditional values have so engrossed our minds that little or no effort to test them were at any time considered necessary. The cost of cultivation is still the heaviest single item in arable farming. Days, when farmers could afford to be artists in matter of cultivation - cross ploughings, harrowings for months on end -are no more. The time is ripe to examine whether, in these days of rising wages and falling prices, tillage costs cannot be cut down or telescoped. Keen [1938] frankly admits that cultivation experiments started in 1927 in full belief that they would provide quantitative data amply confirming the traditional view of cultivation have forced them to conclude that yields are not markedly influenced by cultivation.

The sowing of maize crop after the break of monsoon generally depends on the time available to the farmer for preparing his land. What should be the optimum cultivation for maize and how far the initial deficiency in preparation of land to sow crop in time can be made up subsequently by inter-tilling, are some of the pertinent questions to be answered. Moreover, the plant food requirement of this crop are also high. It is not enough to have right doses of the right fertilizers but the method of their application should be such as to ensure efficient utilisation of manure in an economical manner. Chapman [1946] observed, there was a place for heavy application of fertilisers by the plough sole method.

With this introduction the results of the above investigation carried out in the farm of Indian Agricultural Research Institute, New Delhi, from 1951 to 1954 are given.

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Experimental

The experiment was laid out in a split-plot design with $3 \times 4 \times 3$ combinations, replicated four times, on an irrigated piece of land. Details of treatments are given below :

Treatments

(*a*) *Main-plot* (frequency)

A—Two ploughings

B—Four ploughings

C—Six ploughings

(*b*) *Sub-plot*

1st split (interculture)	2nd split (placement of fertilizer)
W—One hoeing with bullock hoe	P—Plough sole
X—Two hoeings with bullock hoe	K—Lap of furrow
Y—Three hoeings with bullock hoe	T—Broadcast
Z—Removal of weeds by hand hoe (*khurpi*) only.	

Initial ploughing in every case was given with soil-inverting plough followed by ordinary cultivation with local wooden plough.

Five hundred pounds of fertilizer mixture with NPK in the ratio of 1 : 2 : 1 was applied to an acre. In the case of 'plough-sole' the fertilizer was placed with the help of a funnel fitted behind the wooden plough. In the second case the mixture was applied on both sides of the furrow when it was opened. For 'broadcast' treatment the fertilizer was applied on the surface and then mixed with the soil.

Rotation. Maize—peas.

Soil. A heavy soil of good fertility with the following physical composition and chemical constituents was selected for the purpose.

Table I

Mechanical analysis of the soil

Composition	Percentage
Coarse sand	Traces
Fine sand	39·31
Silt	27·94
Clay	30·62

TABLE II

Chemical analysis of the soil

Depth	pH	N	CaO	P_2O_5		K_2O	
				Total	Available	Total	Available
0—6 in.	7·7	0·076	0·83	0·11	0·012	0·82	0·012

RESULTS

As the location of the experiment remained the same during the four years under investigation the data were pooled in order to get a general picture of the period as a whole after eliminating the year to year variations. The response obtained is affected a great deal by seasonal conditions. For example, excellent results were obtained in the first year while the worst in the year following. The serial analysis of data is summarised in Table III.

A. *Main-plot treatments*

TABLE III

Effect of frequency of cultivation on the yield of grain
(md. per acre)

Treatment	Years				Average
	Y1	Y2	Y3	Y4	
A	18·43	8·70	15·43	9·75	13·08
B	18·08	9·69	13·73	11·73	13·31
C	18·24	9·37	13·90	10·33	12·96
Average	18·25	9·25	14·35	10·60	

Years : S. Em $\pm$ 0·28, C.D. at 5 per cent 0·77, C.D. at 1 per cent 1·02, 'F' test Sig. Ploughings—'F' not significant.

It would appear from Table III that seasonal effect is more pronounced than the effect of cultivations. This is not unexpected as the response obtained from treatments depends a great deal on seasonal conditions, which vary from year to year. Due to severe lodging of crop at the time of cob formation in Y_2 and Y_4 the yields were adversely affected.

The difference between the three ploughing treatments were not found to be significant. The yields obtained with A and B are almost the same and a little higher than 'C'. The futility of higher frequency of cultivation is obvious.

B. *Sub-plot treatments*

The effect of inter-tillage on yield which forms the 1st split is given in Table IV.

TABLE IV

Effect of inter-tillage on the yield of maize (md. per acre)

Treatments	Y_1	Y_2	Y_3	Y_4	Average
W	17·85	8·59	13·77	9·51	12·43
X	17·74	9·34	14·36	10·75	13·05
Y	20·12	8·61	14·16	12·46	13·84
Z	17·28	10·49	15·13	9·70	13·15

'F' Sig. at 5 per cent.
C.D. at 5 per cent 0·97.

The differences between the four intercultures were found to be significant at 5 per cent level. The treatments Y (interculture thrice with bullock hoe) and X do not show significant difference between themselves but the treatment 'Y' gave significantly better yield than W. The treatments Z and X do not differ significantly from treatment W.

Table IV amply shows the importance of inter-culturing a monsoon crop like maize. It also indicates the necessity of eradicating weeds adequately and opening up soil by removing cap either with bullock implements or hand hoe. Obviously it would be cheaper to get the job done by the former method.

Sub-sub plot treatments (2nd split)

The effect of the method of application of fertilizers is shown in Table V.

TABLE V

Effect of different methods of application of fertilizers on the yield of grain (md. per acre)

Treatment	Y_1	Y_2	Y_3	Y_4	Average
P	20·85	9·67	14·14	11·91	14·14
K	18·24	8·75	14·14	9·71	12·71
T	15·67	9·34	14·78	10·19	12·49

'F' test Sig. at 1 per cent.
C.D. at 5 per cent 0·45.
1 per cent 0·59.

The differences between the three methods of application of fertilizer are found to be significant at 1 per cent level of significance. The application according to plough sole (P) method gave significantly the highest yield. The other two methods, viz. lap of furrows (K) and broadcast (T) do not significantly, differ from each other.

Interactions

After having studied the main-effects it would be worthwhile to observe the interactions which form a very important study from practical point.

TABLE VI

Effect of ploughing X interculture on the yield of grain (md. per acre)

Treatments	W	X	Y	Z
A	12·91	12·53	14·24	12·63
B	12·36	13·37	13·64	13·86
C	12·02	13·24	13·62	12·95

S. Em ± 0·58
'F' not significant.

Though the interaction between ploughing and interculture treatments is not found to be significant, yet indications are in favour of greater number of hoeings when the initial preparation is not adequate. Two ploughings and 3 hoeings have shown the highest yield followed by four ploughings and hand hoeings. Six ploughings did not react well with the interculture as there is downward trend in yields.

TABLE VII

Effect of ploughing X method of application of fertiliser (yield in md. per acre)

Treatments	P	K	T
A	13·98	13·33	11·91
B	14·09	12·73	13·11
C	14·35	12·07	12·46

S. Em ± 0·31　　C.D. 5 per cent 0·87.
1 per cent 1·15
'F' Sig. at 1 per cent.

It appears from Table VII that interactions between ploughing and method of application of fertiliser are significant. All the three ploughings gave higher yields with plough-sole (P) method, but the treatment B and C in conjunction with the treatment P gave significantly better yields than with treatments K and T, whereas the difference between the treatment combinations AP and AK is not significant although AP combination is significantly better than the AT combination of treatments. The differences between the treatment combinations BK and BT or CK and CT are not significant.

TABLE VIII

Effect of interculture X method of application of fertiliser (yield in md. per acre)

Treatments	W	X	Y	Z
P	13·70	13·92	14·89	14·06
K	11·91	12·78	13·35	12·80
T	11·68	12·44	13·26	12·60

S.Em ± 0·36
'F' test not significant.

Although the above interactions are not significant yet the plough sole treatment with 3 hoeings has given the highest yield.

The triple interaction is not significant.

DISCUSSION

The grain yield has not been found to be significantly affected by the frequency of ploughings. It seems plausible to infer from the findings of this study that yields are insensitive to variation in the frequency of tillage for seed-bed preparation. But the response becomes marked when interculture is restored during the growing period of the crop. The response is more with highest intensity of the hoeings making the treatment 'Y' significant over 'W'. There was no significant difference between other treatments. The frequent hoeings also helped in the eradication of weeds completely. Moreover, the significant increase in case of three hoeings as compared with other treatments may also be explained in the light of the fact that this was generally the stage when phenologic activity of plants had begun. The better air-moisture relationship at this period was conducive to better cob and grain formation.

The method of application of fertiliser in localised zones ensured quick availability of nutrition to plants which reflected favourably on the grain yield. It is evident that the placement methods exposed the nutrients to lesser fixation [Russell, 1950] and thus better availability. The good results obtained in the case of plough sole are, mainly due to fact that the uptake of fertilisers by the plants was made easy and assured. The proximity of nutrition to plant roots helped to feed the plants well—[Chapman, 1945]. Other workers including Scarseth *et al* [1943], Caldwell [1944], Pitner [1946], Turk *et al.*, and Bear [1941] favour the plough sole placement of fertilizers.

Although the interaction between ploughings and intertillage was not found to be significant yet some important indications have been noted. It has been clearly brought out from this study that fine preparation of seedbed is not so important as the subsequent handling of crop. This is of great practical value as during short spells of fine weather during the monsoon one should not aim at a high perfection in tillage for seedbed preparation but should try to sow the crop timely as any deficiency in the initial preparation of land can easily be made up by subsequent interculture. This is evident from yield obtained with two-ploughing and three-hoeing treatments in this experiment. By adopting this procedure not only high yields are secured but also larger areas could be covered with greater production of food. The other economic advantage of this practice is the cutting down of costs as ploughings are costlier than hoeings.

Interaction between ploughing and method of placement of fertilizer was found to be significant. The highest yields were obtained from the plough-sole treatment and the lowest with surface application under all intensities of cultivation. The treatment 'P' gave significantly higher yield over 'K' and 'T' in the 'B' and 'C' treatments. It may, however, be seen that placed application has, on the whole, been better with cultivation treatments than top-dressing.

The effect of interculture in combination with the method of application of fertilisers was not found to be significant. But the combined effect of the two outstanding treatments namely 'P' and 'Y' which have individually given highest yields was also found dominant here. The highest yield of 15 md. grain per acre was obtained with this combination.

Summary and Conclusion

In general, the results of these studies have shown that variation in the frequency of cultivation did not affect the yield of maize crop. For a *kharif* crop like maize, the removal of weeds and aeration of soil during the period of growth is more important than the initial preparation of the seedbed. The results have indicated that any deficiency in tillage for seedbed preparation could be made up by subsequent hoeings during the life cycle of crop. This may also prove cheaper.

The placed manner of fertilizer use through plough-sole method has been observed definitely better than other methods of application tried.

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THE NITROGEN REQUIREMENT OF SUGARCANE IN MYSORE

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SUGARCANE is cultivated in all parts of Mysore State, where facilities for irrigation during summer are available, the annual acreage being about 50,000 acres. Roughly 25 per cent of the crop raised is used for the manufacture of sugar and the rest converted into jaggery (*gur*). While it is cultivated in every part of the State, large areas are developed for sugarcane only in tracts served by river channels, of which the Visweswariah Canal Tract in Mandya District and the Vani Vilas Sagara tract in Chitaldrug District are typical. While soils in different sugarcane tracts differ in texture, colour, and composition, they are. in general, low in organic matter and nitrogen and to a lesser extent in available P_2O_5 but are well supplied with potash and lime. Narasimha Iyengar [1934] gives the following values for soils of the Visweswariya Canal Tract, which may be taken as typical of sugarcane soils in general.

N per cent	P_2O_5 per cent	Available P_2O_5 per cent	Exchangeable K_2O per cent	Exchangeable CaO per cent
0·02 to 0·04	0·007 to 0·048	0·0002 to 0·02	0·0085 to 0·077	0·02 to 1·10

LITERATURE REVIEWED

The importance of nitrogen for high yields of sugarcane was recognised early and Indian workers have devoted considerable attention to the study of the problem of nitrogen requirement, the manures and fertilisers best suited for the purpose, and their effect on yield and quality of the crop.

Cliff [1930] in Bihar, Lander and Narayan [1935] in the Punjab and Sethi [1936] in U. P. found that sugarcane responded to liberal applications of green manures followed by top dressings of ammonium sulphate and oil cakes. Rege [1943, 1954], recommends the liberal use of bulk manures, particularly compost, when high doses of nitrogen are applied as ammonium sulphate. Varahalu and Ramiya [1938] found differential responses to oil cakes and ammonium sulphate. Iyer and Pande [1954] found that continuous use of inorganic fertilisers without the application of green manure and compost caused deterioration of the soil. Kapur and Kishore [1951] studied the comparative efficiency of organic and inorganic fertilisers and

found that the latter produced better yields. Lad, Bapat and Patel [1954] report that an application of ammonium sulphate and oil cakes in the ratio of 1:1 to be the best in Bombay. Gahlot [1954] in a comparative study of ammonium sulphate, ammonium nitrate and sodium nitrate found them to be equally effective at equal nitrogen levels. Rao [1954] found that nitrogen in the form of NH_4SO_4 became more quickly available than oil cakes.

The quality of juice in relation to application of nitrogen has been studied by Harrison [1927] who found that while potash improved quality, nitrogen depresses it. Reheja [1950] reported that while high doses of nitrogen improved yields, C.C.S. values were lowered. Similar findings have been reported by Rege [1950] and by Rao and Narasimham [1951]. Singh and Ramakrishna [1948] found that early plantings benefitted more than late plantings by applications of nitrogen.

By and large, nitrogen seems to be the main factor determining sugarcane yields. Studies on phosphate requirement by Rege [1950], Laxmikanthan [1954] and Tandon and Kapoor [1954] have shown that there is generally no direct response to phosphate except in certain soil types. Chaterjee [1943] found that nitrogen is the limiting factor for sugarcane in Bengal. In reviews of manurial work in India, Rege [1939] and Mukerjee and Verma [1947] conclude that nitrogen is the limiting factor in so far as cane yields are concerned.

Earlier work in Mysore. In Mysore, the first experiments on manuring sugarcane were concerned mainly with the use of artificial fertilisers as a top dressing over a basal application of bulk manure. Single fertilisers like superphosphate and ammonium sulphate and compound fertilisers like ammophos and niciphos were tested, singly and in combination with one another. Experiments [*Ann. Repts.* 1926-1930] at Babbur and Marthur Farms indicated that compound fertilisers offered no advantage over mixtures of single fertilisers, as the relative proportion of plant nutrients in them were not optimum to our soil conditions. There was a ready response to nitrogen, an application of 500-750 lb. of ammonium sulphate being considered necessary under Babbur Farm conditions. Phosphates at low doses had no effect but applications of 350 to 500 lb. of concentrated superphosphate (150—200 lb. of P_2O_5) seemed to enhance yield. Potash was found to be quite unnecessary.

Later experiments at Hebbal showed that heavy doses of nitrogen could be used with advantage. According to Badami [1932] 2 cwt. of superphosphate, 6 cwt. of ammonium sulphate and one ton of oil cakes were required under Hebbal conditions and produced yields up to 70 tons. At the Visveswaraya Canal Farm (till recently known as Iroin Canal Farm) in the newly opened V. C. Tract, a large number of experiments on sugarcane manuring were laid out. On this farm, the soils are particularly poor in organic matter, and ammonium sulphate was, therefore, used with caution, 3 to 5 cwt., only being used in the first series of experiments. Results of experiments [Narasimha Iyengar 1934], however, showed that doses up to 10 cwt. could be used with advantage without any injury to the soil or detriment to the

quality of the crop. These experiments also brought out the importance of bulk manures to build up soil fertility and improve yields. Coleman [1934] advocated the liberal use of compost, both as soil improver and source of nitrogen.

The experiments described in this article are a continuation of the work cited above, and cover a period of ten years from 1936. The experiments were carried out at V. C. Farm and Babbur Farm representing two important channels—irrigated tracts and at Hebbal Farm representing tank irrigated conditions and have been recorded from time to time in official reports [1936-1946] by Narayanan, and by Rao.

Procedure

The experiments were laid out according to standard designs and the results were subjected to statistical analysis. The crop under all experiments was raised under normal conditions of tillage, irrigation, seed rate, spacing and cultivation as recommended by the Agricultural Department. The maturity of the crop was followed by analysis of cane samples collected from each treatment from the 10th month to the time of harvest. Harvest was done when the crop was fully ripe. Yield of cane and C.C.S. per acre were recorded in each case but differences between treatments are judged on the basis of cane yields only.

Methods of cultivation. In all experiments reported, the method of cultivation has conformed to the standard practices recommended by the Agricultural Department. The field was ploughed four to six times to bring it to the required tilth and plough furrows were opened three feet apart. Selected three budded setts were planted at 10,000 setts per acre and irrigation was given once a week till germination was complete and thereafter once in 10 to 12 days, as required. No irrigation was given during the rainy season. The crop received two earthings up, once at 6-8 weeks after planting and again at 12-13 weeks, weeds being removed by manual labour, before each earthing up.

Bulk manures like compost and farmyard manure were incorporated during final ploughing. Green manure when applied was grown *in situ*, and incorporated 3 to 4 weeks before planting cane. Fertilisers were given in 3 doses (except where stated otherwise) once at planting time, and again at the two earthings up.

The time of planting and harvest, and the quantities of bulk manures and fertilisers applied are indicated separately under each experiment.

Soil and climatic conditions at the Experimental Station. The soils of the Visveswaraya Canal Farm are sandy loams with a clay content of less than 30 per cent. They are well drained, but poor in organic matter, and nitrogen and available phosphoric acid is also low. The average values are N :·02 to ·04 per cent ; P_2O_5 : ·002 to ·02 per cent ; exchangeable K_2O: ·008 to 0·077. The rainfall in the area averages 25 inches and the rainy season is confined to the period June to November.

At the Hebbal Farm, where the annual rainfall is about 30 inches the soils are a clay loam typical of the well established soils under tanks, the clay content of the soil being about 50 per cent. The composition of the soil is N-0·05 per cent available P_2O_5—0·005 per cent : exchangeable K_2O : 0·06 per cent.

At Babbur Farm, the rainfall is about 25 inches and is well distributed. The rainy season commences in June and continues up to the end of November, the heaviest precipitation being during September-October. The soils are sandy to clayey loams, with a layer of soft, decomposing rocks at the subsurface. The occurrence of lime *kankar* in the subsoil is also common. The composition of the soils is N-0·02 to ·08 per cent, available P_2O_5-0·008 to 0·08 per cent : exchangeable K_2O-0·01 to 0·10 per cent.

Varieties tested. During the period of these experiments, H.M. 320, was the dominant variety in the V.C. Tract and this has been used in most experiments on V.C. Farm. Many of the trials have been designed to include two or more varieties, including H.M. 320, so as to study the interaction between variety and manurial treatments. At Babbur Farm H.M. 647, either alone or with one or two other varieties has been used.

The experiments described here, relate to, (1) Optimum dose of nitrogen supplied as ammonium sulphate, (2) optimum dose of nitrogen supplied as groundnut oil cake, (3) optimum proportion of organic and inorganic forms of nitrogen, (4) optimum dose of nitrogen supplied as a standard mixture of organic and inorganic forms, and (5) Study of the interaction between N, P and K.

(1) *Experiments on the optimum dose of nitrogen supplied as ammonium sulphate*

In three trials at V.C. Farm, applications of increasing levels of ammonium sulphate over a basal dose of bulk manure were compared. In the first of these, the levels compared were, 10,12, 17 and 22 cwt. of ammonium sulphate per acre ; in the other two trials, the levels tested were 10, 15, 20, 25 and 30 cwt. per acre. The data are summarised in Tables I and II.

TABLE I

Yield of cane and sugar at different levels of application of NH_4SO_4 at V. C. Farm

Treatment	Cane (tons per acre)	Sugar (tons per acre)	Remarks.
10 cwts. of Am_2SO_4	33·5	3·75	40 lb. of P_2O_5 as superphosphate and 120 lb. of N as compost were given as common treatment to all the plots
12 ,, ,,	45·9	5·97	
17 ,, ,,	37·1	4·74	
22 ,, ,,	42·9	5·33	

Critical difference at P : 0·5 :0·597.

Date of Planting : 5-4-1938.

Date of harvest : 27-7-1939.

The ammonium sulphate was given in three equated doses at planting, first earthing up and final earthing up.

The yield of cane under 12 and 20 cwt. is significantly higher than that under 10 cwt. and that under 15 cwt. over 10 cwt. approaches significance. C. C. S. per cent cane is depressed by applications higher than 17 cwt.

TABLE II

Yield of cane and sugar per acre under increasing levels of ammonium sulphate at V. C. Farm

(*Variety : H.M. 320*)

	A	B	C	D	E
N as bulk manure	150	150	150	150	150 lb.
N as ammonium sulphate	250	350	450	550	650 lb.
Total nitrogen	400	500	600	700	800 lb.
Experiment 3					
Cane (tons per acre)	38·1	46·3	50·1	52·5	51·[illegible]
Sugar (tons per acre)	5·52	6·72	6·84	6·49	6·47
C. D. at 5 per cent level	5·13 tons				
Experiment 4					
Cane (tons per acre)	36·6	52·7	54·6	51·5	55·8
Sugar (tons per acre)	5·31	7·48	7·46	6·69	7·03
C.D. at 5 per cent level	3·26 tons.				
Date of planting	10-8-39				
Date of harvest	30-9-40				

Common treatment. 120 lb. N as compost ; 80 lb. P_2O_5 as superphosphate 80 lb. K_2O as K_2SO_4 at planting. Ammonium sulphate was given as follows: 50 lb. of N at planting, 100 lb. at first earthing up, 100 lb. at final earthing up and the rest at 100 lb. each time at intervals of four weeks.

In both experiments, the data on yield of cane indicate that differences in yield are highly significant. The yields at all levels higher than 400 lb. per acre are significantly better than that at 400 lb. ; but differences between 500, 600, 700 and 800 lb. are not significant.

Sugar yields are depressed by applications higher than 500 lb. of N per acre. This is due to a lower sucrose content and higher reducing sugar in the juice at harvest, with a consequent low value of C.C.S. per cent cane. It was also observed that the crop under 600, 700 and 800 lb. of N lodged badly and side-shooting was profuse.

Thus, it is seen that there is no distinct improvement in yield of cane and there is actually a loss of sugar at levels of application higher than 500 lb. of N per acre.

Optimum dose of nitrogen supplied as groundnut oil cake

This series of experiments was carried out to determine the optimum dose of groundnut oil cake as a source of nitrogen for sugarcane. The experiment was repeated at all the three stations, over several seasons. The experiment was laid out on a different field each year taking care, however, that the soils and the crop history of the fields selected were similar.

At V.C. Farm, the levels compared were 150, 200, 250, 300, 350 and 400 lb. of N as groundnut oil cake over a basal application of compost and green manure calculating to 100 lb. of nitrogen. The oil cake was given in three equal doses at planting, at first earthing up and final earthing up. The experiment was repeated over five seasons, using the variety H.M. 647.

The mean yield of cane in tons per acre obtained and C. C. S. per acre, in trials at V.C. Farm are indicated in Table III.

TABLE III

Yield of cane and C.C.S. in tons per acre under increasing levels of nitrogen supplied as groundnut oil cakes at V.C. Farm

(Variety : H.M. 647)

			1	2	3	4	5	6	
N as groundnut oil cake (lb.)			150	300	250	300	350	400	
Total N including green manure and compost (lb.)			250	300	350	400	450	500	
Experiment No.	Season	Yield tons per acre							C.D. at 5 per cent levels
5	1942-43 27-11-42/15-4-44	Cane C.C.S.	34·53 4·50	35·20 4·56	35·79 4·68	38·80 5·11	37·91 4·88	37·3 4·88	6·9 tons
6	1943-44 27-3-43/25-5-44	Cane C.C.S.	49·95 6·79	46·30 6·23	50·49 6·63	50·38 6·63	48·72 6·43	50·6 6·78	9·0 ,,
*7	1944-45 (summer) 8-2-44/15-5-45	Cane C.C.S.	9·41 1·23	11·54 1·47	11·55 1·49	11·55 1·58	12·59 1·61	14·50 1·78	5·9 ,,
8	1944-45 (winter) 17-10-44/15-2-46	Cane C.C.S.	11·83 1·45	19·58 2·35	15·54 1·80	15·54 1·92	15·63 1·91	21·58 1·62	5·6 ,,
9	1945-46 30-7-45/25-10-46	Cane C.C.S.	16·50 2·24	18·15 2·49	18·55 2·64	18·55 2·38	19·29 2·67	18·6 2·39	7·3 ,,
	Average	Cane C.C.S.	24·44 2·70	26·15 2·85	26·96 2·87	26·96 2·44	26·83 2·92	28·5 2·91	

*Owing to some local difficulty in obtaining enough irrigation water the crop suffered in the initial stages of growth.

The difference in yield between different levels of N, are not significant in any trial, and doses higher than 150 lb. as groundnut cake have failed to produce a corresponding increase in yields.

H.M. 647 is a vigorous variety, which in bulk cultivation under a manurial dose of 400 lb. of N per acre consisting partly of oil cakes and partly of ammonium sulphate gives yields of 40-45 tons per acre. The yields obtained in these experiments are, however, seen to be low. The low yields obtained are due, partly at least, to the inability of the crop to utilise to the full the nitrogen supplied by the oil cake. This association of low yields with lack of ammonium sulphate in the fertiliser mixture, is observed in another experiment. (Experiments 18, 19 and 20 described later in the article.)

The wide difference in yield under the same treatment in different years is due, no doubt, to variations in climatic and other factors, but the relative yields between the several treatments follow the same pattern, there being no significant increase over that at the basal level of application of oil cakes.

In trials of Babbur Farm the levels of application compared were 50, 100, 150, 200, 250 and 300 lb. of N per acre as groundnut oil cake over a basal application of compost and green manure calculating to 100 lb. N. per acre. The results obtained with trials repeated over three seasons are summarised in Table IV.

TABLE IV

Cane and sugar yields at different levels of N applied as groundnut oil cake at Babbur Farm

(*Variety : H.M. 647*)

			1	2	3	4	5	6	
N as groundnut oil cake			50	100	150	200	250	300 lb.	
Total N including green manure and compost (lb.)			150	200	250	300	350	400 lb.	
Experiment No.	Season	Yield tons per acre							C.D. at 5 per cent level
10	1943-44 24-12-43/18-4-45	Cane C.C.S.	10·9 1·44	14·40 1·91	14·30 1·96	20·80 2·47	21·90 2·91	21·50 2·86	5·4 tons
11	1944-45 20-12-44/6-2-46	Cane C.C.S.	8·64 1·17	12·23 1·68	13·35 1·78	16·45 .212	17·20 1·21	20·89 2·58	2·5 ,,
12	1945-46 1-12-45/20-2-47	Cane C.C.S.	9·16 1·21	10·85 1·37	12·44 1·57	19·45 2·47	17·79 2·28	15·89 1·98	6·52 ,,
	Average	Cane C.C.S.	9·56 1·27	12·49 1·65	13·38 1·77	18·88 2·44	18·96 2·46	19·43 2·44	

Unlike at V.C. Farm, the differences in yield between different levels of N are significant but differences between 200, 250, and 300 lb. of N supplied as groundnut oil cake are not significant. This would indicate 200 lb. of N per acre as groundnut cake (300 lb. N total) as the optimum for this area. The yield obtained at 200 lb. and higher levels is fairly satisfactory though somewhat low for this farm, indicating, a better utilisation of the nitrogen of the oil cake.

At Hebbal Farm the levels of N as groundnut oil cake compared were 100, 150, 200, 250, 300 and 350 lb. per acre over a basal application of 100 lb. N per acre as green manure and compost. The cane yields from trials repeated over three seasons are summarised in Table V.

Table V

Yield of cane, in tons per acre, under different levels of N applied as groundnut oil cake at Hebbal Farm

(*Variety*: *H.M. 647*)

N as groundnut oil cake (lb.)			150	200	250	300	350	400 lb.	
Total N including compost and green manure (lb.)			250	300	350	400	450	500 lb.	
Experiment No.	Season	Yield tons per acre							C.D. at 5 per cent level
13	1943-44 25-2-43/24-4-44	Cane C.C.S.	39·86 ..	46·53 ..	51·24 ..	46·81 ..	50·36 ..	53·46 ..	4·3 tons
14	1944-45 5-2-44/5-3-45	Cane C.C.S.	29·90 3·86	30·90 3·86	30·60 3·59	30·90 3·99	34·00 4·20	26·60 4·56	6·6 ,,
15	1945-46 6-2-45/15-4-46	Cane C.C.S.	19·10 2·40	22·20 2·81	21·80 2·88	25·00 3·10	21·00 2·62	25·00 3·21	5·6 ,,
	Average	Cane C.C.S.	29·62 3·13	33·21 3·33	34·54 3·23	34·22 3·55	35·12 3·41	35·02 3·88	

The treatment effects in two (Experiments 2 and 3) out of the three trials are not significant. The yields also, are comparatively low in two out of the three trials, indicating an inability on the part of the crop to utilise fully the nitrogen of the oil cake.

Optimum proportion of inorganic and organic forms of nitrogen

A combination of organic and inorganic forms of nitrogen provides the best answer to the dual needs of soil conservation and high yields. To determine the optimum proportion of these two forms, combinations containing ammonium sulphate, compost and oil cakes in various proportions, were compared in a series of trials. In two of these at V.C. Farm, combinations of ammonium sulphate and

compost at a level of application of 500 lb. of N per acre were compared. The results are summarised in Table VI.

TABLE VI

Yield of cane in tons per acre under different combinations of compost and ammonium sulphate at V. C. Farm

N supplied as		Total lbs. per acre	Yield in tons per acre				Critical difference at 5 per cent level	
Compost	Am_2SO_4		Expt. 16		Expt. 17		Expt. 16	Expt. 17
			Cane	Sugar	Cane	Sugar	Tons	Tons
250	250	500	27·61	3·88	20·60	2·67	6·38	8·5
322	188	500	22·52	3·03	18·40	2·37		
375	125	500	22·27	3·12	19·10	2·37		
437	63	500	14·35	2·03	19·10	2·50		
500	*nil*	500	11·03	1·59	13·50	1·50		

The compost was applied in two equal doses. The first dose was given during preparatory cultivation and the rest at final earthing up. Fifty pounds of N as ammonium sulphate, under each treatment was given at planting and the rest in two doses at first and final earthing up. In Treatment 4 where 63 lb. of N are given as ammonium sulphate, the whole of it was applied at planting.

Experiment 16 was started on 26-12-39 and completed on 25-4-41, and experiment 17 on 15-2-40 and 2-4-41 respectively.

The treatment effects are significant in the first trial but not in the other, combinations containing ammonium sulphate are significantly better than only compost. Maximum yields have been obtained in both the cases, with the combination containing half the nitrogen as ammonium sulphate.

In three other trials at V.C. Farm, the nitrogen at a level of 400 lb. per acre was supplied in various combinations of oil cakes, ammonium sulphate and compost. All plots received green manure supply of 25 lb. of N per acre. Under each combination, the inorganic nitrogen was supplied as ammonium sulphate. Half the organic N was given as compost and the other half as oil cakes. The compost was given in two doses at planting and earthing and the oil cakes in a single dose at final earthing up. The ammonium sulphate was given in three doses; 50 lb. of N at planting and the rest at the two earthings up. Two varieties of cane were included in one trial and three in the other two employing a split plot design with six replications. The results are summarised in Tables VII(A) and VII(B).

Table VII(A)

Cane and sugar yields in tons per acre under various combination of organic and inorganic forms of nitrogen at V.C. Farm

	Nitrogen in organic form	Nitrogen in inorganic form	Total N	Yield tons per acre in Experiment 18 (17-7-39/21-10-40)				Yield tons per acre in Experiment 19 (27-11-40/23-6-42)					
				H.M. 320		Co. 419		H.M. 320		Co. 419		H.M. 661	
				Cane	Sugar	Cane	Sugar	Cane	Sugar	Cane	Sugar	Cane	Sugar
A.	Nil.	400	400	47·82	6·62	68·50	8·34	40·48	5·51	47·30	6·42	53·07	6·79
B.	400	nil.	400	33·72	4·70	56·02	6·28	30·03	4·26	40·75	3·36	41·41	
C.	200	200	400	38·04	6·63	69·71	8·03	37·45	5·28	46·32	6·19	49·09	
D.	300	100	400	37·59	5·21	62·73	6·37	32·84	4·57	42·17	5·49	12·72	
E.	No manure	..	..	10·15	1 ·42	25·37	2·28	14·23	1·95	25·02	3·14	22·10	

C.D. at 5 per cent level. Experiment 18 : 5·90 and Expt. 19 : 4·18 tons. Experiment 20 : 8·05 tons.

Table VII(B)

Experiment 20 (5—4—41/15—8—42)

—	Yield tons per acre					
	H.M. 661		H.M. 647		H.M. 320	
	Cane	Sugar	Cane	Sugar	Cane	Sugar
A.	66·19	7·73	55·17	6·57	26·20	3·11
B.	54·77	6·27	34·48	4·24	23·17	2·80
C.	68·05	8·27	55·07	6·55	26·26	3·26
D.	51·52	5·94	34·39	4·07	17·52	2·09
E.	21·97	2·56	14·86	1·79	19·83	2·38

The treatment effects in all the three trials are highly significant. Four hundred pounds of nitrogen in any form has given significantly higher yields than no nitrogen. Combinations C and A are superior to other combinations.

Maximal yields are obtained by applying the whole of the nitrogen as ammonium sulphate or half as ammonium sulphate and the rest as organics. Nitrogen supplied wholly in the organic form is definitely inferior to combinations containing ammonium sulphate indicating the necessity for ammonium sulphate or inorganic source of nitrogen for proper yields.

The results of two similar trials at Babbur Farm are given in Table VIII

TABLE VIII

Yield of cane and sugar in tons per acre under different combinations of organic and inorganic forms of nitrogen at Babbur Farm

N. in organic form lb.	N. in inorganic form	Total lb. N.	Yield tons per acre Experiment 21 No. 19-1-40/12-3-41				C. D. at 5 per cent level
			H.M. 607		Co. 290		
			Cane	Sugar	Cane	Sugar	
A. Nil.	400	400	24·67	2·95	24·31	2·93	3·82
B. 400	Nil	400	16·30	2·08	15·90	2·01	
C. 200	200	400	22·11	2·65	22·49	2·77	
D. 300	100	400	17·11	2·20	16·95	2·07	
No manure	..	..	7·81	0·99	8·02	1·08	

N. in organic form lb.	N. in inorganic form	Total N. lb.	Yield tons per acre Experiment 22 19-1-40/12-3-41				C. D. at 5 per cent level	
			H.M. 607		Co. 290		N.M. 647	
			Cane	Sugar	Cane	Sugar	Cane	Sugar
A. Nil	400	400	22·55	2·62	25·20	2·63	21·30	2·77
B. 400	Nil	400	25·81	3·07	20·84	4·35	21·33	2·55
C. 200	200	400	19·76	2·30	22·07	2·54	23·55	3·01
D. 300	100	400	20·56	2·47	20·04	2·30	18·38	2·31
No manure	..	..	20·01	2·25	16·89	1·98	16·16	2·12

The treatment effects are significant, nitrogen in any form being significantly better than no nitrogen. Combinations A and C are better than the others. The effect of the application of the whole of the nitrogen in the organic form is, however, not so poor as at the V.C. Farm.

While further confirmation may be necessary it may be assumed, that under Babbur Farm conditions, nitrogen in the form of oil cakes is more readily utilised than at V.C. Farm.

The interaction between varieties and treatments was not significant, nor was there any correlation between treatment and C. C. S. per cent cane in any of the experiments on any farm.

Optimum dose of nitrogen supplied as a mixture of organic and inorganic forms in equal parts

In the preceding section it was seen that a mixture containing half the nitrogen in the organic form and the other half in the inorganic form is quite as good as all the nitrogen supplied in the inorganic form. In the interest of soil conservation, a mixture of the forms is to be preferred to the inorganic fertiliser alone. Two trials at V.C. Farm in which different levels of nitrogen were compared, the nitrogen at each level being given as a combination of equal parts of organic and inorganic nitrogen generally confirm these findings. In the first of these, nitrogen at levels of 300, 400, and 500 lb. per acre was compared using three varieties; in the second, the levels of nitrogen were 300, 350, 400, and 450 lb. per acre with two varieties of cane. A split plot design with 5 replications was employed in each case. The nitrogen was given half as ammonium sulphate and half as oil cakes, the oil cakes being applied at final earthing up and the ammonium sulphate in three equal doses as in other experiments. (Table IX).

In the first trial, the treatment effects are significant, the levels 400, and 500 lb. being significantly better than 300 lb. but the difference between 400 and 500 lb. is not significant.

In the second trial the treatment effects are not significant, although the highest yields are obtained at 450 lb. N. per acre.

Interaction between varieties and levels of nitrogen were not significant, and there was no noticeable difference on the C.C.S. per cent cane due to the treatments.

Two trials on similar lines were carried out at Babbur Farm where the levels of N. compared were 100, 200, and 300 lb. per acre (Table X).

The treatment effects are significant, in both trials, 300 lb. of N per acre being significantly better than 100 lb. and 200 lb. per acre, the difference between 100 and 200 lb. being not significant. Three hundred pounds of N per acre is obviously necessary for maximal yields at Babbur Farm.

Table IX

Yield in tons per acre under different levels of nitrogen supplied as a mixture of equal parts of organic and inorganic forms at V.C. Farm

Level of N. lb.	Experiment 23 (13-12-40/31-3-42)						C. D. at 5 per cent level	Level of N. lb.	Experiment 24 (20-10-42/30-11-43)				C.D. at 5 per cent level
	H.M. 320		No. 419		Co. 661				H.M. 320		H.M. 64		
	Cane	Sugar	Cane	Sugar	Cane	Sugar			Cane	Sugar	Cane	Sugar	
300	22·52	2·76	47·48	5·82	39·04	4·58	3·82	300	32·30	4·30	43·06	5·67	3·6
400	29·64	3·72	46·32	5·59	48·28	5·74		350	32·73	4·35	44·02	5·80	
500	31·64	3·78	52·32	6·35	41·41	5·85		400	31·09	4·15	43·19	5·78	
								450	33·97	4·64	45·98	6·06	

Table X

Yield of cane and sugar in tons per acre under different levels of N supplied as a mixture of equal parts of organic and inorganic forms at Babbur Farm

Level of N lb.	Yield tons per acre Expt. 25 (7-9-42/28-11-43)				C.D. at 5 per cent level	Level of N. lb.	Yield tons per acre Expt. 26 (5-11-42/25-11-43)				C.D. at level
	Co. 290		H.M. 647				Co. 290		H.M. 647		
	Cane	Sugar	Cane	Sugar			Cane	Sugar	Cane	Sugar	
100	24·70	3·08	21·49	2·93	4·65	100	35·89	..	27·74	..	4·10
200	24·31	3·11	21·52	2·91	tons	200	37·01	..	35·03	..	tons
300	31·88	4·01	27·08	3·68	..	300	39·37	..	48·06	..	

Interaction between N, P and K

In experiments discussed so far, the effect of different levels, combinations, and forms of N have been studied, an adequate amount of P and K being supplied as a common basal dressing under all nitrogen treatments. The interaction between N, P and K at three different levels of each, has been studied in two experiments, one at Babbur Farm and one at V.C. Farm using a 3^4 factorial design.

The level of N, P, K and varieties included at each farm are shown below :

	Level of N			Level of P			Level of K		
	No.	N1	N2.	Po	P1	P2	Ko.	K1	K2.
V. C. Farm	400	500	600	50	75	100	50	75	100
Babbur Farm	150	250	350	0	40	60	0	50	100

One hundred pounds of N. under all levels were supplied as green manure (25 lb. N) and compost (75 lb. N) and the rest as ammonium sulphate in 3 equated doses. The K_2O and P_2O_5 were supplied as sulphate of potash and superphosphate, respectively and applied in one dose at planting.

Varieties :

V. C. Farm — H.M. 320, Co. 419, H.M. 544,

Babbur Farm — H.M. 607, Co. 290 purple Mauritius.

At both farms, the nitrogen effects alone are significant, the effect of different levels of P and K and interactions between P, K and N not being significant. The interaction between varieties and treatments were also not significant.

Taking the effects of different levels of N, it is seen that at V.C. Farm, 500 lb. N is better than 400 lb. and the difference between 500 and 600 lb. is not significant. At Babbur Farm, 250 lb. of N per acre is significantly better than 150 lb. but there is no difference between 250 lb. and 350 lb. per acre. These results fix the maximum doses of N for V.C. Farm at 500 lb. and for Babbur Farm at 300 lb. a result in conformity with that obtained in other experiments.

A study of analytical data on juice samples at V.C. Farm, showed that nitrogen levels higher than 500 lb. generally had a depressing effect on C.C.S. per cent cane.

Discussion

The results of experiments reported here offer a fair basis for the formulation of a manurial schedule for the major sugarcane tracts of Mysore State. In Experiments 27 and 28 where the interaction between N, P and K is studied, it is seen that there is no response to application of phosphates at the levels studied, *viz*. 50, 75 and 100 lb. of P_2O_5 at V.C. Farm and 0·40 and 60 lb. of P_2O_5 at Babbur Farm. This is in general agreement with results of earlier experiments in Mysore, as well as in the rest of India. The main factor interaction is given in Table XI.

TABLE XI

V.C. Farm. (11-3-39/20-4-40)

Variety	Nitrogen (lb.)			P_2O_5 (lb.)			K_2O (lb.)			Mean	Increase
	400	500	600	50	75	100	50	75	100		
H.M. 320	28·88	30·86	30·95	31·21	28·11	31·36	28·81	31·96	28·92	30·23	..
Co. 419	48·66	48·64	47·72	46·08	45·56	48·38	47·14	45·91	46·96	46·67	16·44
H.M. 544	32·16	37·34	35·53	35·95	34·70	34·38	34·42	35·65	34·96	35·01	4·78
Mean	34·90	38·07	37·72	36·12	38·01	36·79	37·84	37·84	37·28	..	..
Increase	..	4·05	..	1·60	0·29	..	1·05	0·49	..	..	..

(Babbur Farm. 28-9-40/18-12-42)

Variety	Nitrogen (lb.)			P_2O_5 (lb.)			K_2O (lb.)			Mean	Increase
	150	250	350	0	40	60	0	50	100		
H.M. 607	9·58	17·48	19·33	16·36	41·56	15·46	15·22	16·37	15·80	'15·46	..
Co. 290	14·90	19·86	20·99	18·05	18·50	19·20	16·93	19·34	19·47	18·58	8·12
Purple Maritius	4·74	6·90	7·95	6·54	6·74	6·36	7·00	6·73	5·85	6·53	8·29
Mean	9·74	14·75	16·09	13·65	13·27	13·30	13·05	13·81	13·71	..	..
Increase	..	5·01	5·35	..	–·38	–·35	..	–·76	0–·66	..	..

The main factor in relation to sugarcane yields is nitrogen. As in other parts of India, increasing doses of nitrogen produce higher yields of cane and tend to depress sugar content; but in Mysore deterioration in quality is noticed only when the total nitrogen exceeds 400 lb. per acre. In this respect, the position is somewhat similar to that prevailing in Bombay where according to Rege [1950] increasing cane tonnage has been obtained with increasing nitrogen up to 375 lb. N, but from the point of view of sugar yields 300 lb. N has been recommeded. Rao and Narasimhan [1951] have stated that in Madras there was no improvement in yield beyond 100 lb. N and there was a depression in sucrose in juice. Considering the yields obtained in the experiments with increasing doses of ammonium sulphate, 500 lb. of nitrogen, including the basal application of bulk manures seems to be the safe limit, consistent with the quality of juice. This will work out to approximately 15 cwt. of ammonium sulphate per acre.

Experiments with groundnut oil cake as a source of nitrogen for sugarcane have shown that both under V.C. Farm and Hebbal Farm conditions there is no response to applications at levels higher than 150 lb. N as oil cakes. The position is somewhat different at Babbur Farm. The actual yields have varied widely from year to year due probably to climatic differences and other factors, but the trend of response to increasing doses of oil cakes has been similar in all cases. With ammonium sulphate as the source of nitrogen, significant increases are obtained at V.C. Farm even up to 500 lb. of N and thus the inability of the soils to utilise to the full the nitrogen in the oil cakes is apparent. This is seen also in the experiments (Experiments 18 and 19) where 400 lb. of N as oil cakes has given significantly lower yield than an equal amount of N supplied as ammonium sulphate or a mixture of ammonium sulphate, oil cakes and compost. The causes contributing to this difference have not been studied in detail but it has been observed that applications of ammonium sulphate stimulate tillering and early vigour, which no doubt contributes to a better yield.

The form of nitrogen best suited seems to be a mixture containing equal parts of organic and inorganic nitrogen. The data (Experiments 18, 19, 20 and 21 and 22) no doubt show that yields are equally good when all the nitrogen is supplied in the inorganic form. But knowing that the soils are poor in organic matter, it does not seem worthwhile to adopt a manurial schedule based entirely on ammonium sulphate.

Experiments with nitrogen supplied as a mixture of equal parts of organic and inorganic N (Experiments 23, 24, 25 and 26) have shown that 400 lb. of N for V. C. Farm and 300 lb. N for Babbur Farm conditions to be optimum and this may be taken as the basis of manuring in these tracts.

Conclusions

(1) The nitrogen requirement of sugarcane in Mysore is fairly high and varies from place to place. Yields are influenced both by the dose and the form in which the nitrogen is supplied. Oil cakes and compost are inferior to ammonium sulphate, but they can replace the latter to the extent of 50 per cent of the total nitrogen requirement without detriment to yield and quality.

(2) Under V.C. Farm conditions it is seen that :

(*a*) Ammonium sulphate can be applied with advantage up to 15 cwt. per acre (300 to 350 lb. of N) over a basal application of compost, calculating to 120-150 lb. of N. Higher doses of ammonium sulphate tend to reduce the sugar content and do not produce an appreciable increase in cane yield,

(*b*) Oil cakes by themselves are not suitable as a source of nitrogen for sugarcane on this farm,

and (*c*) maximum yields can be obtained with a basal application of green manure and compost (100 lb. N per acre) followed by 20 to 300 lb. of N in the form of oil cakes and ammonium sulphate in equal parts.

(3) At the Babbur farm, oil cakes are utilised better than at V.C. Farm. Fair yields can be had by the application of compost and green manure (100 lb. N) followed by oil cakes (200 lb. N per acre).

As in V.C. Farm maximum yields are obtained by the application of compost and green manure (100 lb. N) followed by 200 lb. of N in the form of oil cakes and ammonium sulphate in equal parts.

Summary

The results of certain field trials on the manurial requirement of sugarcane carried out on three experimental Stations in Mysore, viz. V.C. Farm, Babbur Farm and Hebbal Farm, are reported.

The nitrogen requirement of sugarcane in Mysore is fairly high and varies from 300 lb. of N at Babbur Farm to 400-450 lb. at V. C. Farm. The response to nitrogen is influenced both by the dose and the form in which it is supplied. Nitrogen supplied wholly in the organic form (oil cakes and compost) is inferior to ammonium sulphate, but mixtures containing not less than 50 per cent of the total N in the inorganic form are quite as good as wholly in organic nitrogen. For routine practice, a basal application of green manure and compost calculating to 100 lb. N per acre, followed by oil cakes and ammonium sulphate in equal proportion to make up the balance is recommended.

Application of nitrogen at levels higher than 500 lb. per acre tend to depress sugar content.

No significant interaction between nitrogen treatments and varieties was observed.

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STUDIES ON ROUGHAGES IN KAIRA DISTRICT (BOMBAY STATE)

CHEMICAL COMPOSITION OF WHEAT FODDER (*TRITICUM SATIVUM*)

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THREE varieties of wheat, viz. Niphad (irrigated and non-irrigated), Pusa and Kenphad are grown in the district of Anand. The Bhal tract, which includes Matar and Cambay talukas has heavy black soil and hence is suitable for growing non-irrigated variety of Niphad wheat. In the Charotar area which includes Anand, Borsad, Petlad and Thasara talukas, the soil being *goradu* (sandy loam type) the irrigated varieties of Niphad and Pusa wheat are grown. Kenphad wheat is a rust-resistant variety recently introduced in comparatively small areas.

The present investigation deals with the composition of the fodder at different stages of growth and also of the straws of different varieties grown in different years. Though the common practice is to utilise straw of wheat crop for feeding the cattle, the samples of the fodder at various stages were also analysed with a view to note the extent of variations in the composition of the fodder at different stages of maturity.

Experimental

(A) *Method of sample collection*

Samples of the fodder at different stages of growth were collected from four representative villages in the area within about 12 miles radius from Anand. Each village was divided into four blocks and samples were taken from several places in each block. All the material from the four blocks was mixed and a composite sample was taken to represent the village. The samples were chopped and milled into powder before analysis.

(B) *Methods of analysis*

A. O. A. C. [1950] methods of analysis were followed.

Results and Discussion

The composition of Niphad wheat (irrigated) fodder collected in 1953 at dough and mature stages is given in Table I followed by the results of the statistical analysis of the data.

TABLE I

Composition of Niphad wheat (irrigated) fodder at specified stages from different villages

Village	Karamsad		Napa		Radhu		Budhej	
Stage	Dough	Straw	Dough	Straw	Dough	Straw	Dough	Straw
C. Protein	5·00	3·94	6·69	1·65	5·21	2·48	8·62	2·45
E. Extract	0·96	2·10	1·47	1·59	1·09	1·27	1·96	1·29
N. F. E.	58·48	36·41	57·36	48·98	50·25	42·40	58·99	41·76
C. Fibre	26·05	47·30	26·15	37·75	31·20	35·00	21·73	43·75
Ash	9·51	10·25	8·33	10·08	12·25	18·85	8·70	10·75
Silica	5·93	5·42	4·73	5·72	8·69	14·65	6·53	5·75
Phosphate (P_2O_5)	0·57	0·46	0·63	0·30	0·62	0·39	0·75	0·42
Calcium (CaO)	0·32	0·57	0·46	0·47	0·39	0·69	0·39	0·25

Stage	C. Protein	E. Extract	N.F.E.	C. Fibre	P_2O_5	CaO
Dough	6·38±0·84	1·37±0·22	56·27±2·03	26·28±1·94	0·64±0·04	0·39±0·03
Straw	2·63±0·48	1·56±0·19	42·39±2·57	40·95±2·80	0·39±0·03	0·50±0·09
"t" value	3·91**	0·63	4·23**	4·31**	5·00**	1·16

**Significant at 1 per cent level.

The results in Table I indicate that as the fodder attains maturity the protein and N.F.E. contents decrease by about 50 per cent and 25 per cent respectively and its fibre content increases by 50 per cent. With regard to minerals, the phosphate content significantly decreases, while the tendency for calcium content is to inrease with maturity. The number of samples were too small to bring out the significance of the latter.

The trend of variation in the nutrients with maturity is similar to that observed in *jowar* fodder (Part I by the present authors 1956) except in N.F.E. which has an increasing tendency in *jowar* fodder. The decrease in N.F.E. content of wheat fodder is in agreement with the trend reported by Nath and Das [1953] in case of grasses they studied.

The composition of Niphad wheat (non-irrigated) fodder collected in the same year at different stages of growth is given in Table II together with the summary of the statistical analysis.

TABLE II

Composition of Niphad wheat (non-irrigated) fodder at specified stages from different villages

Village	Budhej		Limbasi		Rahdhu		Traj	
Stage	Dough	Straw	Dough	Straw	Dough	Straw	Dough	Straw
C. Protein	12·30	3·26	8·56	3·33	10·45	4·48	10·61	3·77
E. Extract	2·23	2·10	2·23	1·39	2·60	2·32	1·99	2·60
N. F. E.	64·28	49·74	64·95	47·08	63·48	46·41	68·83	45·73
C. Fibre	14·96	33·60	12·97	28·40	17·35	30·76	12·70	30·30
Ash	6·23	11·30	11·29	19·84	6·10	15·82	5·87	17·30
Silica	3·42	7·01	8·66	14·92	2·94	13·18	3·67	12·47
Phosphate (P_2O_5)	0·84	0·22	0·75	0·17	0·75	0·19	0·69	0·29
Calcium (CaO)	0·42	0·54	0·22	0·45	0·44	0·60	0·43	0·49

Stage	C. Protein	E. Extract	N. F. E.	C. Fibre	P_2O_5	CaO
Dough	10·48±0·76	2·26±0·12	65·38±1·36	14·50±1·08	0·76·±0·03	0·38±0·06
Straw	3·71±0·28	2·10±0·26	47·24±0·68	30·48±0·96	0·22±0·03	0·52±0·03
"t" value	8·25**	0·55	12·10**	11·36**	5·87**	2·19

**Significant at 1 per cent level.

The data in Table II reveal that the observations made in the case of the irrigated variety also hold good for this variety. The increase in calcium content with maturity also approaches significance in the non-irrigated variety.

The decrease in nutrients from the dough to the straw stage is considerable and hence it is possible that if the crop is harvested without any delay after maturity, the quality of the fodder obtained would be superior.

On comparing the composition of the irrigated and non-irrigated varieties of wheat fodder, it can be seen that the fodder of the non-irrigated variety is superior as far as proximate nutrients are concerned.

In Table III are presented the results of analysis of Pusa wheat fodder collected in 1953 at different stages and they have also been analysed statistically.

From Table III it may be concluded that the differences between samples collected from different villages are not significant, while the differences between the nutrient contents at different stages of growth are highly significant. The protein content of the fodder at the young stage is very high, almost similar to leguminous green fodders. The mineral contents at that stage are also considerably high. The trend of change in crude protein, crude fibre and phosphate is similar to that observed

in the case of Niphad wheat fodder (irrigated or non-irrigated). The calcium content, however, gradually decreases as against the increasing trend observed in Niphad wheat fodder. It is remarkable that in Pusa wheat fodder the N.F.E. content increases up to its dough stage and then declines in the straw stage.

TABLE III

Composition of Pusa wheat (irrigated) fodder at specified stages from different villages

Village	Bhalej			Karamsad			Chaklasi			Boriavi		
Stage	Young	Dough	Straw	Young	Dough	Straw	Young	Dough	Straw	Young	Dough	Straw
C. Protein	25·30	5·76	1·35	24·20	9·38	3·30	26·90	5·60	3·90	28·65	10·02	1·98
E. Ext.	3·70	1·84	1·79	3·54	1·72	1·81	2·71	1·57	1·09	2·66	2·46	1·37
N. F. E.	34·30	57·84	37·89	35·33	52·12	39·62	30·78	46·71	43·46	30·60	48·10	49·99
C. Fibre	24·50	27·10	50·60	22·58	31·00	45·50	21·97	36·50	42·60	22·70	28·20	38·92
Ash	12·20	7·46	8·37	14·35	5·78	9·77	17·64	9·62	8·98	15·20	11·22	7·74
Silica	2·04	4·72	5·19	3·22	2·57	5·80	4·85	5·90	9·48	4·60	4·95	5·42
Phosphate (P_2O_5)	1·33	0·69	0·13	1·38	0·63	0·16	1·95	0·46	0·31	1·48	1·27	0·23
Calcium (CaO)	0·90	0·28	0·22	0·91	0·48	0·40	1·08	0·40	0·35	0·83	0·46	0·46

Stage	C. Protein	E. Extract	N. F. E.	C. Fibre	P_2O_5	CaO
Young	26·26	3·15	32·75	22·94	1·54	0·93
Dough	7·69	1·90	51·19	30·70	0·76	0·40
Straw	2·63	1·52	42·74	44·40	0·21	0·36
F. Value						
Villages	1·11	1·56	0·20	0·65	0·73	1·30
Stages	182·14**	18·58**	12·58**	29·03**	22·82**	40·00**
L. S. D. at 5 per cent (Stages)	3·18	0·69	9·00	6·99	0·48	0·17

**Significant at 1 per cent level.

As Kenphad wheat is a recently introduced new variety, it has not yet taken up sufficient acreage. Hence samples from only one place were collected in 1953. The results of analysis are given in Table IV.

TABLE IV

Composition of Kenphad wheat (irrigated) fodder from village—Bhalej

Stage	C. Protein	E. Extract	N. F. E.	C. Fibre	Ash	Silica	P_2O_5	CaO
Dough	8·09	3·73	55·76	25·87	6·55	3·34	0·72	0·28
Straw	4·38	1·15	44·30	41·90	8·27	2·60	0·22	0·53

As can be seen from Table IV, the trend of change in the composition of the fodder with progressive maturity is similar to that observed in other varieties.

TABLE V

Comparison of straws of different varieties (1953) (From four places)

Variety	C. Protein		E. Extract		N. F. E.		C. Fibre		P_2O_5		CaO	
	Av.	S.E.	Av.	S.E.	Av.	S.E.	Av.	S.E.	Av.	S.E.	Av.	S.E.
Niphad (Irrigated)	2·63	0·48	1·56	0·19	42·39	2·57	40·95	2·80	0·39	0·03	0·50	0·09
Niphad (Non-irrigated)	3·71	0·28	2·10	0·26	47·24	0·68	30·84	0·96	0·22	0·03	0·52	0·03
Pusa (Irrigated)	2·63	0·58	1·51	0·17	42·74	2·63	44·41	2·51	0·21	0·05	0·36	0·05

On comparing the Niphad irrigated and non-irrigated straws it may be observed that the phosphate content in the former is more than that in the latter. This observation is similar to that made by Murphy [1936], who has stated that high rainfall is associated with high phosphorus content. The difference in the crude fibre contents of the two is appreciable and hence it may be said that the straw of irrigated variety is more fibrous than that of the other.

When the straw of Niphad irrigated variety is compared with that of Pusa irrigated variety, it can be seen that the former is richer in minerals than the latter.

The crude fibre content of irrigated Pusa wheat straw is much higher than that of non-irrigated Niphad wheat straw. This is in agreement with the observation made above in comparing the straws of irrigated and non-irrigated varieties of Niphad wheat.

The composition of non-irrigated Niphad wheat straw collected during three years (1952 to 1954) from different villages is given in Table VI. The standard errors have been calculated so that a comparison between the averages can be made. The number in brackets represents the number of villages from where samples have been collected.

TABLE VI

Comparison of non-irrigated Niphad wheat straw of three years

Year	C. Protein	E. Extract	N. F. E.	C. Fibre	P_2O_5	CaO
1952(2)	$3·48\pm1·23$	$1·54\pm0·14$	$45·86\pm3·19$	$31·80\pm0·90$	$0·44\pm0·04$	$1·14\pm0·42$
1953(4)	$3·71\pm0·28$	$2·10\pm0·26$	$47·23\pm0·88$	$30·84\pm1·06$	$0·22\pm0·03$	$0·52\pm0·03$
1954(4)	$2·20\pm0·13$	$1·37\pm0·16$	$47·51\pm1·76$	$34·34\pm1·38$	$0·29\pm0·11$	$0·40\pm0·05$
't' value for 1952 and 1953	0·18	1·87	0·42	0·33	2·62	1·47
1953 and 1954	4·83**	2·40*	0·14	2·02	0·65	2·00

*Significant at 5 per cent level
**Significant at 1 per cent level

The results in Table VI reveal that the straw of 1952 does not differ from that of 1953 except that the former is richer in minerals than the latter. The crude protein and ether extract contents of the fodder of 1954 are definitely lower than those of the fodder of 1953. Although statistical significance is not obtained, it may be pointed out that the mineral content of the samples of 1953 and 1954 is lower than that of the samples of 1952. This may be attributed to the heavier rainfall in 1953 (29 in.) and 1954 (42 in.) than in 1952 (16 in.). It is in accordance with the finding of Murphy [1936] as far as calcium content is concerned and with the findings of Surin [1941], who has reported that abundant rainfall is associated with a decrease in phosphorus content. However, Ray and Sen [1953] have reported decreased calcium and phosphate contents in the fodders they studied with the decrease in rainfall.

Summary

Fodders of Niphad (irrigated and non-irrigated), Pusa and Kenphad wheat, collected from a number of villages in Kaira district, have been analysed to study the variations in the composition of different varieties and due to different stages of growth. Crude protein and phosphate contents are found to decrease, while crude fibre increases with maturity. The N.F.E. content increases up to dough stage and then decreases. Calcium content tends to increase except in Pusa wheat fodder, in which case it decreases. A comparison of the nutrients in the straws of different varieties reveals that straws of the irrigated varieties are more fibrous than that of the non-irrigated variety. From a comparison of non-irrigated Niphad wheat straw of 1952, 1953 and 1954 it appears that heavy rainfall is associated with low mineral content.

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A NOTE ON SIDE-GRAFTING OF CASHEW (*ANACARDIUM OCCIDENTALE* LINN.)

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THE studies on the vegetative propagation of the cashew conducted at the Central Cashewnut Research Station, Ullal, Mangalore, (since 1953) included trials on side-grafting with and without the aid of Alkathene plastic film. Preliminary trials showed that among the several methods of propagation, air-layering using alkathene film as well as inarching both with and without the aid of the film were successful.

The trials on side-grafting are described in this article.

Four-inch long, pencil-thick terminal shoots from selected trees, precured about a week in advance, were inserted on one year old cashew seedlings in the nursery beds, adopting the Nakamura method. Twenty insertions were made at monthly intervals from April 1955 to March 1956. Observations on the percentage of 'take' showed that except for a single instance in July 1955, there was no other response. The scion shoots were found to shrivel up within 10 to 15 days after insertion.

In order to exploit the moisture retaining property of the Alkathene plastic film the following modification was attempted from October 1955.

Side-grafting as described above was done. About two to three inches above and below the graft joint, slightly moist moss was applied, over which a 6th×5th piece of Alkathene 100-gauge film was wrapped with both the ends secured with twine. A thin muslin was suspended from above to protect the grafted portion from the effects of desiccation due to the sun. With the signs of graft union as indicated by the sprouting of the scion piece, visible through the transparent film, the cloth, the film and the moss were removed in progressive stages. The following observations on the percentage of successful 'take' were recorded.

No. done per month : 20

Month	Percentage of success
October, 1955	15
November, 1955	—
December, 1955	10
January, 1956	10
February, 1956	35
March, 1956	40
April, 1956	70
May, 1956	50
June, 1956	15
July, 1956	25
August, 1956	5
September, 1956	25

It may be seen from the above data that the success is comparatively high between the months of February and May. Considering the fact that the plants propagated in these months are available for planting in the following monsoon season between June and August, this result may be deemed as encouraging. It is also significant that similarly encouraging results were obtained during this period (between March and May) in air-layering and inarching operations also. The fall in the percentage of success after June is similarly a result which has been recorded in the other methods of propagation.

The percentage of success of 40 to 70 though not as spectacular as 80 to 100 per cent secured in air-layering and inarching is, nevertheless, noteworthy, as much labour is saved in side-grafting besides the attractive possibility of an increased turnover within a small area in the nursery. The dependence on scion trees in private plantations attended with the risks of trespass and neglect which are the drawbacks in inarching are also eliminated in side-grafting.

Five grafts out of those raised by side-grafting were planted out successfully in the field in June, 1956 at the Central Cashewnut Research Station, Ullal, Mangalore.

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STUDIES ON THE VEGETATIVE PROPAGATION OF CASHEW (*ANACARDIUM OCCIDENTALE* LINN).

FURTHER STUDIES ON AIR-LAYERING

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EARLIER studies at the Central Cashewnut Research Station, Mangalore, had revealed that air-layering of one year old and current season's shoots with the aid of plastic film wrappers is an easy method of clonal propagation[15,16] of the cashew. Further trials were undertaken in 1954 and 1955, to study in particular the influence of the age of parent trees on rooting of shoots, to determine the optimum position of cut while "ringing" or "cincturing" the shoot, to observe the effects of application of growth regulating substances on the rooting capacity of shoots, to select a suitable and cheap rooting medium, to decide upon the optimum thickness of the plastic film wrapper and to work out the cost of production of the air-layers. The results of these several trials are reported in this paper.

REVIEW OF LITERATURE

The age of the plant from which either cuttings are taken or the shoots of which are layered, exerts considerable influence on the capacity to form callus and root. Investigations at the Maryland Experiment Station are reported by Gardner[8] to have shown that cuttings from one year old seedlings of many kinds, rooted readily whereas cuttings from older plants did so with difficulty or not at all. He holds that nursery trees, too young to bear fruit, are generally used without detriment as a source of buds and scions by commercial nurserymen as they serve as a splendid source because of their healthy, vigorous growth. The only advantage in using bearing trees, he adds, is that there is less opportunity to make mistakes in the identity of the desired varieties. His experiments also showed that rooting decreased with increasing age of the plant from seed. Cuttings from the tips of one year old seedlings rooted readily, whereas, if the seedlings were two years old, even though the one year old wood was used, the percentage of rooting dropped very markedly. He found that in plants cut nearly to the ground after the first year's growth, the resulting growth could be rooted with more success than the one year old wood from the two year old plants not cut back. Vekhov and Iljin[22] studied 600 varieties of trees and shrubs and found that shoots from young plants rooted better than those from older ones. Cheesman and Spencer [5] found that leafy stem cuttings from young, non-bearing cacao plants rooted better than those from more mature trees. Thimman and Delisle[21] confirm that the ease with which roots are formed

on one year wood falls off with increasing age of the tree. Stoutemeyer, *et al.*[21] found that apple cuttings in the juvenile phase rooted very readily but those in mature phases rooted only very little and very slowly. Singh[19] observed a higher percentage of rooting in the younger shoots in air-layering trials with mango.

The study of the various rooting media and their effects on rooting of shoots has been dealt with by several workers. Thorough aeration of the medium has been recognised as an important pre-requisite for aiding rooting of the shoots. The most successful media for the rooting of cuttings have all been of open texture. Bailey[2] and several others stress their preference for sand as a medium for indoor use. Coarse sand or even fine gravel have been advocated because of their excellent drainage and freedom from organic matter bearing organisms which cause rooting. Sand, pumice, peat, peat mixtures, sphagnum moss, fir-wood, soil, oak leaf-soil, saw dust, coal ashes, garden soil, rotten refuse, loamy sand, etc., have been used in rooting cuttings. Chadwick[3] found that the use of sand and peat mixtures rather than sand will often result in a better massing of roots. The senior author[14] obtained best results with sand and tank silt for rooting cuttings of *Panax* species. Narasinga Rao, *et al.*[17] found sand superior to charcoal for rooting cuttings of *Gliricidia maculata*. For propagation by air-layering, sphagnum moss has been generally preferred, because of its sterile condition, high water-holding capacity and lightness in weight. Creech, *et al.*[6] consider it indispensable for air-layering.

It is generally believed that in making cuttings, the basal cut should always be made at the node, the reason advocated being that greater amounts of nutrients are stored at the nodes and as a consequence quicker regeneration of tissues takes place and the adventitious roots are forced out rapidly. In some plants, it has been found that a cut at some other position, above the node or below it will give even better results. Chadwick[4] listed soft wood cuttings into four categories, viz. varieties rooting to best advantage when cut at the node, varieties rooting best when cut one half inch above the node, varieties rooting best when cut half an inch below the node and varieties which are indifferent to basal cut. The senior author[14] obtained better results in rooting cuttings of *Panax*, *Eranthemum* and mulberry with the cut at the node, than half inch below or above it. The position of cut or ringing or cincturing in air-layering of plants does not appear to have been discussed in such details as in plant propagation by cuttings although in respect of the rooting propensities of the shoots, the same principles may be said to hold good for either of the methods of propagation.

Growth regulating substances have been used either to accelerate the rooting in plants already known to root easily or to "induce" rooting of species difficult to be so propagated. So far as air-layering is concerned, the use of these substances has been considered as helpful in propagating some plants which for various reasons cannot be propagated on their own roots by conventional methods. Hanger[10] goes to the extent of stating that only on rare occasions have the control air-layers produced roots without the aid of growth regulating substances. The trials on air-layering with cashew at the Central Cashewnut Research Station, Mangalore[15,16] were, however, successful without the aid of these substances. Their subsequent

trial was only to test their efficacy in improving the rooting, particularly during the season when by the conventional methods, the rooting tended to be poor. Singh [18] reported a high degree of success in air-layering litchi and jack with the aid of "Rootone", a proprietory product.

Among the substances, indole-butyric acid seems to have found much favour. Hanger and Ravencroft [11] obtained best results with indole-butyric acid applied as a dust to the marcot cut, in concentrations up to 8,000 p.p.m. to such plants as *Aluliophyllum* and *Magnolia*. Singh [19] obtained 30 to 37 per cent success in air-layering mango, with one per cent a-naphthalene acetic acid.

In the preliminary trials on air-layering of cashew,[15,16] Alkathene film of 150 gauge was used as wrapper. Due to its special property of inertness, durability and moisture retaining capacity, the film proved to be indispensable. Recent attempts in propagation through marcotting have largely been done with the aid of plastic films, which are available in the market in several gauges of thickness either in sheet or tubular form. Floor [7] states that moisture control with the aid of polythene made it possible to root cuttings in a living room and produce results similar to those obtained in a green house. Lipp [10] used polythene plastic film successfully for propagation of ornamental plants by cuttings. Hanger [10] found plastic film of four, five or six thousandth of an inch thickness, ideal for air-layering hard-wooded plants. Less than four thousandth of an inch was considered too thin and a thickness of seven-thousandth of an inch and more proved too thick and rigid to allow successful water proof end seals to be made.

Material and Methods

The trials dealt with in this article were conducted on cashew trees in plantations adjoining the Cashew Research Station, Mangalore in 1934 and 1955. The details under each of the trials are given below :

Influence of the age of the parent tree. The following age groups of plants were worked for air-layering in December 1954 :

(*a*) Seedlings 6-12 months old
(*b*) Seedlings one year old
(*c*) Trees 2 to 5 years old
(*d*) Trees 5 to 10 years old
(*e*) Trees above 20 years

In treatments (*a*) and (*b*), current season's shoots roughly between six and nine months, green, rounded and about pencil-thick were operated upon while in the other three treatments, both current season's shoots and shoots one year old with greying bark were layered at the rate of ten per treatment. The operation consisted of removing a strip of bark $\frac{1}{8}$—$\frac{1}{4}$ inch wide round the shoot and tying a piece of twine on the cut surface to prevent the ends from callusing over. Moist moss was applied over the wound and a 6 in.$\times$5 in. sheet of Alkathene plastic film, 100 gauge, was wrapped over the moss with both the ends secured tight with twine without allowing any air-spaces on either side. The trial, scheduled to be conducted over quarterly intervals from December 1954, was repeated in March, June and September 1955. The percentage of shoots which rooted successfully as

judged by the number of layers ultimately separated from the tree and the period (in days) taken for rooting as determined by the emergence of roots seen through the transparent plastic film were determined.

(*b*) *Position of cincturing or "ringing"*. To study the rooting response in relation to the position of cut, 10 shoots each of one year old and current season's wood were air-layered by the process described under (*a*) with the ringing done (i) at the node, (ii) half an inch below the node and (iii) half an inch above the node. The trial was initiated in December 1954 and repeated at quarterly intervals till September 1955. The percentage of rooting and the time taken for root production under each treatment were recorded.

(*c*) *Influence of growth promoting substances.* In order to test the influence of the growth promoting substances in the rooting of the shoots, a trial was commenced in 1954 and repeated in March, June and September 1955, as described below :

Ten one-year old and an equal number of current season's shoots were air-layered as described under (*a*) and covered with moss soaked for 24 hours in a dilute solution of Seradix A (1 cc. per litre of water), while in another batch the ringed portion of the shoot was directly dusted with Seradix B_3, a powder. A comparable set of untreated shoots to serve as controls was also layered the same day. Alkathene film, 100 gauge, was used for wrapping in all the batches. During March, June and September 1955, another treatment using double the concentration of Seradix A (2 cc. per litre) was also introduced. Data on the percentage of rooting, the number of primary roots produced per shoot and the length of the roots under each treatment were recorded.

(*d*) *Rooting medium.* With a view to studying the responses in relation to the rooting medium and in particular to see if the moss obtained from the Nilgiris could be substituted by any locally available material, the following media were tried. The operation of air-layering was done as described under (*a*), on one-year old and current season's shoots on adult bearing trees in the neighbouring plantations. In the first batch layered in February 1955, the following media were tried :

1. Moss from the Nilgiris, 2. local moss, 3. saw dust, 4. wood shavings and 5. coconut coir fibre.

The trial was repeated in April 1955, with the above five treatments as well as the following additional media, viz. coconut coir husk dust, sand and a mixture of leaf mould and red earth in equal parts. The mean percentage of success under each treatment was worked out.

(*e*) *Thickness of plastic film wrapper.* In the preliminary trials on air-layering conducted in 1953-54, "Alkathene" film of 150 gauge thickness had been used. In order to test the suitability of other gauges (thickness), air-layering was done with one-year old shoots, from selected trees, in September 1954, with the following gauges of Alkathene at the rate of 10 per treatment.

	Cost per linear yard
	Rs. As. P.
(i) 100 gauge	0—4—6
(ii) 120 gauge	0—5—5
(iii) 150 gauge	0—6—9
(iv) 200 gauge	0—9—0
(v) 300 gauge	0—11—4

TABLE I

Results of air-layering trials with different age groups of cashew trees

	December '54				March '55				June '55				September '55				Mean			
	One-year old		Current season's shoots		One-year old		Current season's shoots		One-year old		Current season's shoots		One-year old		Current season's shoots		Rooting		No. of days	
	No. rooted out of ten	Time taken for rooting (days)	No. rooted out of ten	Time taken for rooting (days)	No. rooted out of ten	Time taken for rooting (days)	No. rooted out of ten	Time taken for rooting (days)	No. rooted out of ten	Time taken for rooting (days)	No. rooted out of ten	Time taken for rooting (days)	No. rooted out of ten	Time taken for rooting (days)	No. rooted out of ten	Time taken for rooting (days)	One-year old	Current season's shoots	One-year old	Current season's shoots
Below one year	—	—	6	30	—	—	10	25	—	—	7	40	—	—	6	30	—	7·3	—	31
One year old	—	—	8	22	—	—	10	22	—	—	6	40	—	—	8	30	—	8·0	—	29
2 to 5 years	5	35	2	35	9	35	9	35	5	50	5	50	9	40	7	40	7·0	5·8	40	40
5 to 10 years	9	35	9	35	9	35	9	35	10	50	5	50	9	40	9	40	9·3	8·0	40	40
Above 20 years	9	50	9	48	10	48	9	48	1	90	—	—	9	55	7	55	7·3	6·3	61	60
Mean	7·7	40	6·8	34	9·3	39	9·4	33	5·3	63	4·6	54	9	45	7·4	39	—	—	—	—

The trial was repeated in October and November 1954 and in March 1955. Observations on the percentage of rooting and nature of roots were recorded.

Results

Influence of the age of the parent tree. A summary of the observations under this trial is given in Table I. The results show that (i) in one-year old seedlings, rooting commenced in the earliest period of 22 days with a mean of 29 days for all the batches, thus rendering it possible to separate the layer within 35 days, (ii) in trees between one and ten years in age, the shoots root and become ready for separation within a period of 45 days whereas in adult trees above 20 years, separation is possible only after 60 days, (iii) there is no appreciable difference between the treatments in the percentage of rooting, (iv) in the month of June, rooting is delayed even in trees below 10 years which agrees with similar observations in other trials by this method, while between the other months difference is not appreciable, (v) there is no appreciable difference between the one-year old and current season's shoots in the period of rooting in respect of trees two years and above, although the shoots of one-year old seedlings have given definite indications of early rooting.

b. *Position of cincturing or "ringing".* Results were obtained as recorded in Table II.

Table II

Results of air-layering position of cincturing or "ringing"

Position of cincturing or ringing	December '54			March '55 (No. rooted out of ten)			June '55 (No. rooted out of ten)			September '55		
	One-year old shoots	Current season's shoots	No. of days for rooting	One-year old shoots	Current season's shoots	No. of days for rooting	One-year old shoots	Current season's shoots	No. of days for rooting	One-year old shoots	Current season's shoots	No. of days for rooting
At the node	10	6	23	9	8	30	3	4	55	9	8	42
Above the node	10	3	35	9	7	38	3	4	65	8	8	50
Below the node	8	4	35	9	7	38	3	2	65	8	8	50

TABLE III

Results of air-layering trials with growth regulating substances

Growth Substance	December '54			March '55			June '55			October '55			Mean		
	Percentage of rooting	Mean No. of primary roots	Mean length of roots (cm.)	Percentage of rooting	Mean No. of primary roots	Mean length of roots (cm.)	Percentage of rooting	Mean No. of primary roots	Mean length of roots (cm.)	Percentage of rooting	Mean No. of primary roots	Mean length of roots (cm.)	Percentage of rooting	Mean No. of primary roots	Mean length of roots (cm.)
Seradix A (1 c.c. per litre)	60	35	4·5	75	26	7·5	45	25	5·0	80	30	5·0	65	29	5·5
Seradix A (2 c.c. per litre)	—	—	—	60	28	11·0	65	26	6·0	90	35	5·0	72	30	7·3
Seradix B_3 (powder)	80	9	4·0	80	15	11·0	30	12	6·0	70	13	5·0	65	12	6·5
Control (Untreated)	85	20	4·0	50	18	11·0	30	16	6·5	70	13	4·6	59	17	6·5

The results indicate that (i) a cut at the node induces earlier rooting and (ii) there is no appreciable difference between the treatments in respect of rooting percentage.

c. *Treatment with growth regulating substances.* The results are summarised in Table III.

The data show that :

(i) the use of growth regulators has resulted in higher success in general, though the differences between the treated and untreated batches are not striking. In March, June and October there has been better rooting in the batch treated with Seradix A ;

(ii) treatment with Seradix 'A' (a product containing indole-butyric acid) appears to induce a larger number of roots ;

(iii) treatment with Seradix 'A' has yielded better results in June, when normally the rooting percentage is low ;

(iv) there is no appreciable difference in the length of roots under the different treatments.

d. *Rooting media.* The results under this trial are summarised in Table IV

TABLE IV

Summary of observations with different rooting media

Sl. No.	Rooting media	February (separated in May)		April (separated in June)		
		One-year old shoots	Current season's shoots	One-year old shoots	Current season's shoots	Mean
		No. rooted out of ten				
1	Moss from Nilgiris	8	7	8	6	7·3
2	Local moss	3	3	1	1	2·0
3	Saw dust	7	5	0	0	3·0
4	Wood shavings	9	9	8	7	8·3
5	Coir fibre	8	6	7	7	7·0
6	Coir husk dust	not done	not done	9	6	7·5
7	Sand	,,	,,	10	8	9·0
8	Leaf mould and red earth in equal parts	,,	,,	2	1	1·5

From the above data it seems possible to conclude that :

(i) Moss (Nilgiris) could be substituted by such material as sand, wood shavings, coir fibre and coir husk dust, which have been found to give as good or even better results ;

(ii) local moss, leaf mould and red earth do not appear to be suitable probably due to their tendency to become sticky ;

(iii) the performance with saw dust has been variable being good in February and poor in April.

It is, however, clear from the good results obtained with as many as five different media that employment of loose, open material such as sand and wood shavings, is advantageous in view of their cheapness and ready availability.

e. *Thickness of plastic film wrapper* : The results under this trial are given in Table V.

TABLE V

Results of trials with different gauges of Alkathene wrapper

Gauge	September '54	October '54	November '54	March '55	Mean
		No. rooted out of ten			
100	10	10	8	8	9·3
120	8	10	6	6	7·5
150	10	8	6	8	8·0
200	5	9	10	6	7.5
300	9	3	8	6	6.5

It may be seen that 100 gauge film could prove as effective or even better than 150 gauge film, allowing thereby for a reduction in costs by about Re. 0-2-3 per each linear yard. Observations on the root characters did not reveal any appreciable difference in the length, thickness and number of roots nor in the time of root emergence in the several batches under study.

f. *Economics* : In the earlier trials[15] the cost of production of a rooted plant worked out to Re. 0-2-10. By adopting some of the above treatments and in particular by employment of the cheaper plastic film, and by economising in other operational costs, it was found possible to reduce the cost of production to two annas per clone.

DISCUSSION

The investigations dealt with in this article refer to the first phase of an attempt to standardize the technique of air-layering in cashew, which has emerged as one of the methods suitable for commercial propagation of clonal material. Being a crop hitherto raised only by seed, and covering vast stretches of vacant lands, most of them consisting of remote, barren hill slopes, the merits of propagation of of cashew through vegetative means have yet to be properly understood by a large cross section of growers. It may not, however, be long before a large demand arises for such material because as stated by Garner [9] "in an orderly world the unpredictable variability of seedling plants will not much longer be tolerated".

Cashew is a crop which can be raised with a minimum of capital outlay, the cost of the seed and plant material required for raising plantations being one of the cheapest items. The attempts to standardize the technique of vegetative propagation at the Central Cashewnut Research Station, Mangalore have had this background and, therefore, had to be designed with the primary object of achieving the best results at the lowest possible cost.

The trials with different age groups of trees, the position of cincturing, and the treatment with growth regulators may be grouped under one set of trials designed to step up the total percentage of success by increasing the extent of root production. The second set of trials with different rooting media and different gauges of Alkathene film wrappers, was primarily intended to economise the cost of production. For an overall appraisal of the results especially in terms of the objectives outlined above, it is necessary to consider these two sets of trials as complementary to one another.

In regard to the influence of the age of parent trees on the rooting of shoots, the results have confirmed the findings of most workers, viz., the younger the tree, the quicker is the tendency of the shoots to produce roots. That the active juvenile phase is the most congenial period for taking cuttings for rooting has been proved beyond any doubt. It is however, debated whether such a procedure is desirable in the interests of the future orchard life of trees raised in this manner. Gardner [8] says that except for the fact that the choice of adult trees assures the parentage there is nothing else in their favour. On the other hand, he says, young plants form an admirable source of scion material, particularly when required for raising rooted cuttings and that rooting diminishes with the increased age of the tree. In the current investigations, this question does not arise as the data bring out the superiority of one to 10 year old trees over trees aged 20 years and above. Between one and 10 year old trees the difference in percentage of rooting is not striking though the period of availability of layers is slightly earlier in the younger seedlings. Moreover, a period of 10 years is long enough to judge the performance of a cashew tree and there can therefore be no objection to the choice of six to ten year old trees as scion material in preference to old trees.

Cincturing or ringing or the removal of the bark at the node has given evidence of earlier root production. No special advantage was however, noticeable in the matter of overall success in rooting. Nevertheless, even in so far as the earliness of rooting is concerned the results may be said to accord with the general belief that there is a greater amount of carbohydrates stored at the node than above or below it. It is also likely that the nodal region may have a greater number of root primordia than the inter-nodal regions. This aspect will require further study. Earliness in rooting is also a desirable feature for commercial production of layers, specially when the scion parents are scarce. A succession of layers can be raised from a single tree within a short period if the rooting is quicker.

The use of growth regulating substances has helped in promoting the rooting in June and July when under the normal conditions, it was generally poor. It seems also likely that higher concentrations, as those employed by Hanger and Raven Croft [11] may yield better results. The encouraging response to their use is a sufficient indication that by their use the rate of root production can be increased. It may also be necessary to consider that air-layering of cashew under conditions different from those obtaining in the West Coast, may not necessarily prove quite as successful. In such situations the use of the growth substances may prove helpful or even essential. Since very small quantities of these substances are sufficient to produce the desired effects, it may be even prudent to adopt the use of these

substances as a normal practice to ensure earlier and better rooting. Indole-butyric acid is in general favour among the growth regulating substances and even in these trials, Seradix A (a product containing indole-butyric acid) has given the best results.

Although the use of moss from the Nilgiris was efficient, considerations of economy may overrule its wider or general use on the West Coast. It is gratifying therefore to note that any loose material which would afford sufficient aeration and "room" for unrestrained development of the rootlets would do quite as well as this moss. It has incidentally been observed that media which tend to become sticky and hard are best avoided. The low rooting obtained with leaf mould and red earth mixture, is perhaps due to the hard consistency of the medium inside the wrapper. Wood shavings, one of the promising media, are available in plenty, a bag of nearly 50 lb. costing only about eight annas. In regard to sand, although the results have been quite encouraging, it has to be mentioned that the wrapping of the film with sand as a medium may present some difficulty and may therefore reduce the total outturn. A mixture of wood shavings and sand may perhaps prove more efficient.

The trials with the different gauges of Alkathene, have revealed that the use of 100 gauge film resulted in a saving of as much as Re. 0/2/3 per linear yard of the film. The trials have also shown that the use of films thicker than 150 gauge is both unnecessary and uneconomical.

On a general consideration of the results described above, it will be apparent that (i) selection of a scion parent between six to ten years, (ii) cincturing (ringing) at the node, (iii) use of growth substances such as indole-butyric acid (1 or 2 cc. per litre), (iv) employment of rooting media like wood shavings, sand or coir fibre, and (v) use of 100 gauge "Alkathene" plastic film, may be considered as the optimum for securing the best results at a reasonably cheap rate in air-layering of cashew.

Summary

The progress of further trials on air-layering of cashew between 1954 and 1955 at the Central Cashewnut Research Station, Ullal, Mangalore have been reported in this article. The following are the results :—

(1) In trees below 10 years, the shoots rooted earlier than those in trees 20 years old and above. In one year old seedlings, rooting commenced within the shortest period of 22 days rendering it possible to separate the layer from the parent tree within 35 days.

(2) Cincturing (ringing) at the node was found to induce quicker rooting in shoots than cincturing half an inch above or below the node.

(iii) Application of growth regulating substances such as Seradix A gave indications of a higher success, larger number of roots and better rooting in the months of June and July, when the response was poor without their use.

(iv) Among eight different rooting media, wood shavings, coconut coir husk, coir husk dust, and sand proved to be the best, while material which tended to develop a sticky condition proved unsuitable.

(v) Among five gauges of Alkathene film from 100 to 300 gauge, the 100 gauge proved the cheapest and best.

(vi) The cost of production of layers worked out to Re. 0-2-0 each.

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*Not seen in original

ON THE EFFECT OF CERTAIN ENVIRONMENTAL CONDITIONS ON INFECTION WITH THE BACTERIAL ROOT-AND STALK-ROT DISEASE OF MAIZE

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(With 4 Text-Figures)

The bacterial root- and stalk-rot disease of maize, caused by *Erwinia carotovora* f. sp. *Zeae* Sabet, has recently been reported from Egypt (Sabet, 1954, *a*). The disease is similar to that reported from India [Prasad, 1930], Australia [Ludbrook, 1942] and North America [Rosen, 1926] in many diagnostic features but the causal organism is somewhat different. It is most conspicuous on the stalks and roots of the plants towards maturity, but may also affect the leaves and ears causing a soft rot of these organs. Seedling-rot constitutes a phase of the disease which seems to show itself under certain soil and environmental conditions. Sabet [1954, *b*] has further pointed out that many of the maize varieties which show relative resistance to the disease during the summer growing season (March-July) are much less resistant during the " Nile " growing season (July-October).

In the present investigation, certain soil and environmental conditions which may predispose maize seedlings and plants to the disease are studied.

Materials and Methods

Effect of soil conditions on seedling rot

The soil most frequently used was composed of air-dried Nile deposit silt *plus* fine sand 1 : 1 per volume. The soil was distributed in No. 3 canning tins, 1 kg. in each, and autoclaved at 1·5 atmosphere for 2 hours. To prepare the inoculum for each tin, a 24 hours old broth culture of the maize pathogen was poured on 12 gm. of chopped raw potato in sterile petri dishes, incubated for 24 hours at 35°C and used thereafter. The soil was inoculated by thorough mixing the upper 4 cm. deep layer with the inoculum. Ten germinating seeds of G 102 maize variety were planted in each tin at a depth of about 2 cm. Five tins were so prepared for each treatment and experiments were generally repeated once. The tins were incubated at 35°C for 10 days during which the soil moisture was maintained at 80 per cent of its water-holding capacity, unless otherwise stated.

Temperature. Seeded tins prepared as above were incubated at 20°, 25°, 27°, 30°, 32°, 35°, 37°, and 40°C. The moisture content of the soil was maintained at 80 per cent of its water-holding capacity. The pH value of the soil was 8·4.

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Moisture. Calculated amounts of water were added to the tins to equal 98, 90, 80, 70, 60 and 50 per cent of the soil water-holding capacity. Maintenance of moisture at the various levels was done by calculation of the average loss per container due to evaporation and supplying the calculated amount periodically to the soil, generally once on the fifth or sixth day after setting up the experiment. Tins were incubated at 35°C and the *p*H value of soil was 8·4.

*p*H *value.* With the addition of N/10 sulphuric acid, a lot of Nile deposits was acidified to *p*H 2·9. Mixtures of this and non-acidified soil (*p*H 8·4) were made to bring their *p*H values to 4·7, 5·3, 6·5, 7·4 and 8·4. The soil was distributed in tins, then prepared, and inoculated as above. The soil moisture was held at 80 per cent of its water holding capacity, its *p*H value was 8·4 and the tins were incubated at 35°C.

Texture. The following five soils and mixtures were prepared and their water-holding capacity as an index for their mechanical composition was determined:

Mixture	Water-holding capacity
	Per cent
Fine sand	10
Fine sand+Nile deposits	20
Nile deposits	30
Loam+Nile deposits (light loam)	34
Loam	38
Heavy loam	52

The soil was distributed in the tins and inoculated as above. Two bifactorial experiments were set up to determine the effect of soil texture at (i) different temperatures, viz. 30°, 32°, 35° and 37°C and (ii) different moisture levels, viz. 50, 60, 70, and 80 per cent of the water-holding capacity of each soil mixture. The soil moisture in (i) was maintained at 80 per cent, and the tins in (ii) were incubated at 35°C., the *p*H value of the soil in both instances was 8·4.

Water-saturation period. For the study of the effect of saturating infested soil with water for different periods on subsequent infection, sand Nile deposits soil was distributed in the tins, inoculated as above and saturated with tap water for 1, 2, 5, and 10 days. The soil was then allowed to dry for 3 days after which germinating maize seeds were planted.

Effect of atmospheric temperature and humidity on relative susceptibility to the disease

Potted 30-day old plants of K 55 and G 102, representing very susceptible maize varieties, and K 64 and American Early, representing relatively resistant varieties, were used. Inoculations were made with the aid of a sterile pipette by placing 1 ml. of a thick watery suspension of the bacteria from 48-hour old nutrient agar cultures into the folds of the uppermost leaf. Twenty plants (5 in a pot) of each

variety were inoculated in each treatment. In the study of the effect of moisture, the plants were exposed to high relative humidity for different periods. They were watered and covered with glass bell jars for 6, 24, 48, 72 and 96 hours during which the temperature was about 32°C. For the study of the effect of temperature, inoculation experiments were made at room temperature during March (20°-26°C.), October (26°-34°C) and July (34°-40°C). The plants were covered after inoculation with glass bell jars for 24 hours.

Experimental Results

Effect of soil conditions on seedling rot

Infection in young seedlings took place at, or just below, the soil level and exhibited itself as soft brown lesions on the coleoptile. Many seedlings failed to emerge from the soil (i.e. pre-emergency rot). The results are expressed as means of the percentage of infected seedlings under each treatment in two replicate experiments.

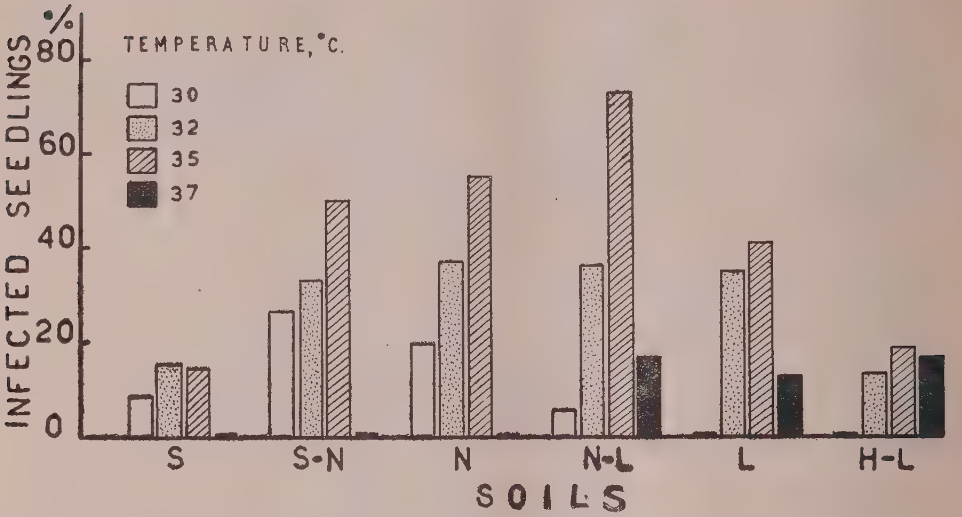
Temperature. The percentages of infected seedlings at 20°, 25°, 27°, 30°, 32°, 35°, 37°, and 40°C were 0, 15, 15, 36, 40·2, 53, 9 and 0 per cent respectively. The optimum temperature for the development of seedling rot was 35°C. Infection incidence was highest at temperatures between 30° and 35°C and dropped sharply at lower or higher temperatures.

Moisture. The percentages of infected seedlings at soil moisture levels of 50, 60, 70, 80, 90, and 98 per cent of the soil water-holding capacity were 32·5, 45, 55, 40·5, 4·5 and 0 per cent. The optimum soil moisture for the development of seedling rot was 70 per cent. Infection incidence gradually decreased at lower moisture levels, but dropped sharply at higher levels.

p*H value.* The percentages of infected seedlings at *p*H values 4·7, 5·3, 6·5, 7·4 and 8·4 were 0, 4·5, 38, 45·5 and 51 per cent respectively. The incidence of infection rose steadily as the *p*H value increased. Such rise was steeper upto *p*H 6·5 and slowed down somewhat after that point.

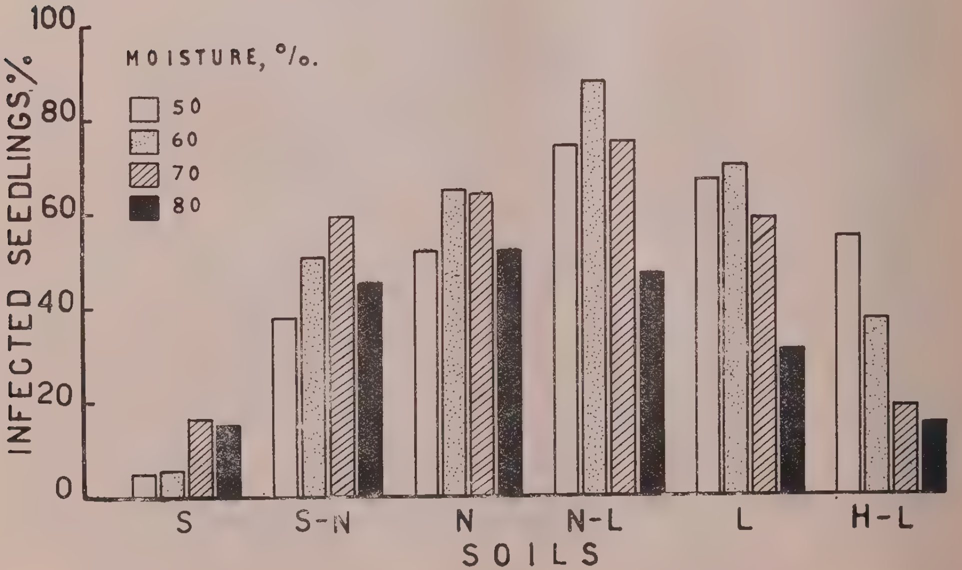
Texture. The soil most favourable for the development of seedling rot at the standard temperature and moisture (35°C and 80 per cent moisture) was the Nile deposits plus loam mixture (i.e. light loam). At lower temperatures and higher moisture levels (Figs. 1 and 2), lighter soils gradually became more suitable than heavy ones. On the other hand, at higher temperatures and lower moisture levels relatively heavy soils became more suitable. Thus while the optimum temperature and moisture were 32°C and 70 per cent moisture in sand, they were 35°C and 50 per cent moisture in heavy loam soil.

Water-saturation period. Infection incidence dropped sharply from 43·5 per cent in soil previously saturated for one day to 20·5 per cent in soil saturated for 2 days and to 4 per cent in that saturated for 5 days. Infection was completely checked in soil saturated for 10 days.



S—sand, N—Nile deposits, L—Loam, H—Heavy.

FIG. 1. Effect of soil texture at varying temperatures on the incidence of seedling rot



S—sand, N—Nile deposits, L—Loam, H—Heavy.

FIG. 2. Effect of soil texture at varying moisture levels on the incidence of seedling rot

Effect of atmospheric temperature and humidity on relative susceptibility to the disease

Three types of infection were recognized during the five days following inoculation; (i) watersoaked lesions not more than 2 cm. long (+); (ii) longer water-soaked lesions which might involve the whole leaf blade and sheath (++); and (iii) dead plants (+++).

Susceptibility to the disease increased with the increase in temperature and time of exposure to high atmospheric humidity (Figs. 3 and 4). The difference between resistant and susceptible varieties was most marked when the plants were kept at lower temperatures or exposed for shorter period to high relative humidity. With increasing time of exposure to high humidity, however, the resistant maize varieties (K 64 and American early) were badly infected. The four varieties of maize (including the resistant ones) became equally susceptible to the disease when exposed for four days.

Discussion

Disposition to seedling rot caused by *E. carotovora* f. sp. *zeae* heightens with increasing soil temperature and moisture up to 35°C and 70 per cent moisture, and drops sharply at higher temperatures and moisture levels. Neutral or slightly alkaline soil is more favourable for the development of the disease than acid soil. Seedling rot is most severe in light loam soil as compared with lighter or heavier types. The mechanical composition of the soil, however, seems to influence temperature-moisture relations of the disease. Maximum infection takes place at 32°C and 70 per cent moisture in sand, but at 35°C and 50 per cent moisture in heavy loam soil. Also, infection is possible at lower temperature limit and higher moisture levels in sand, but at higher temperature and lower moisture levels in heavy loam. This interaction between soil texture, temperature and moisture is primarily due to the influence of the water-holding capacity of the soil. Thus, the lower limits of temperature and higher levels of moisture at which infection is possible in sand is due to its lower water-holding capacity which allows in one way more heat absorption and in another better aeration of soil-borne bacteria. In heavy loam soil, the opposite conditions prevail.

Water-saturation of infected soil is followed by a marked drop in subsequent infection with seedling rot. Flooding the soil for ten days has completely checked the disease under the experimental conditions.

The value of the effect of soil flooding on subsequent infection lies in its being an easy measure for controlling the disease in infested areas. A method based on the same principle has proved to be effective in limiting the black-arm disease of cotton (*Xanthomonas malvacearum*) in Sudan [Dowson 1949].

Infection with the stalk-rot disease is favoured by high atmospheric temperature and humidity. Prolonged exposure to high atmospheric humidity favours the disease in a way so as to render the relatively resistant varieties (e.g. K 64 and American Early) as badly infected as the very susceptible varieties (e.g. K 55 and G 102). This may explain why many varieties that resist the disease during the dry summer season may be infected during the "Nile" growing season, in which

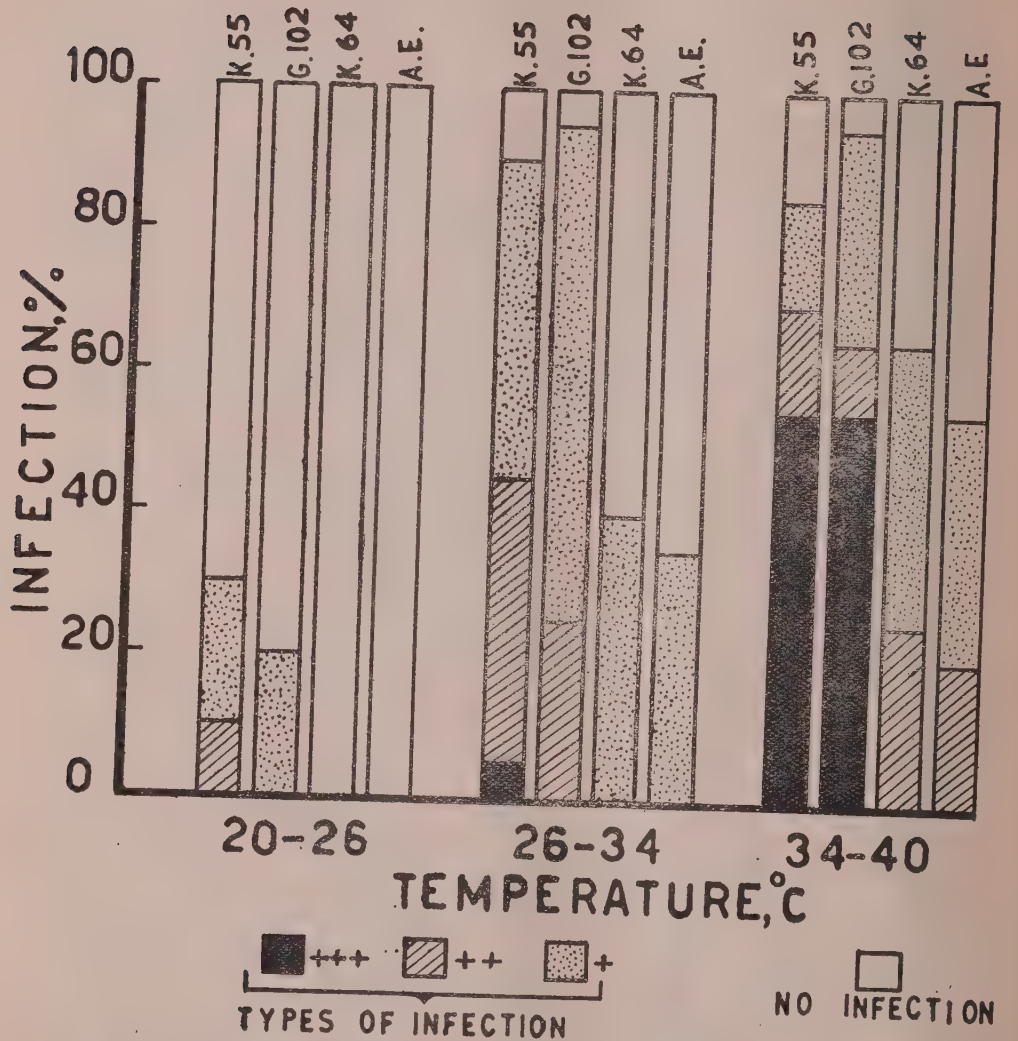


FIG. 3. Effect of atmospheric temperature on relative susceptibility of K55, G102, K54 and American Early (A. E.) maize varieties to stalk rot disease

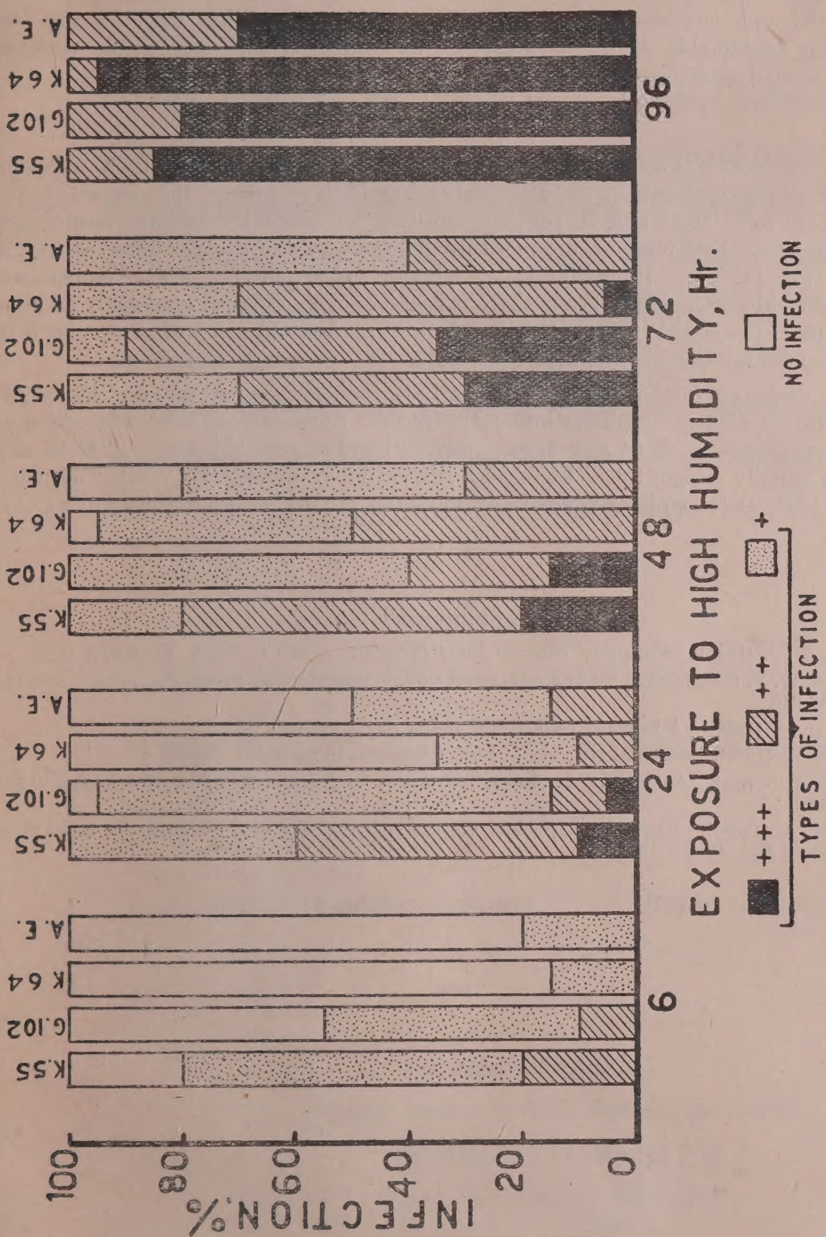


Fig. 4. Effect of exposure to high atmospheric humidity for different periods on relative susceptibility of K55, G102, K64 and American Early (A.E.) maize varieties to stalk-rot disease

high atmospheric humidity prevails for much longer periods. It is to be noted that, although hot weather also favours the disease, resistant varieties will still show an appreciable degree of resistance as compared with susceptible varieties under similar conditions.

Summary

The effect of soil conditions on the development of seedling rot due to infection with *Erwinia carotovora* f. sp. *Zeae* Sabet has been studied. It is shown that in light loam soil, 35°C, and 70 per cent moisture are about the optimum conditions for infection. Soil temperature-moisture relations to the disease differ according to the soil texture. In lighter soils, infection takes place at lower temperature limits and higher moisture levels than in heavier soils. Neutral or slightly alkaline soil is more favourable than acid soil. Saturating infested soil with water for 5-10 days checks subsequent infection.

The disease is further favoured by high atmospheric temperature and humidity. Exposure to high atmospheric humidity for four days renders relatively resistant maize varieties (e.g. K 64 and American Early) and susceptible ones (e.g. K 55 and G 102) equally susceptible. Increasing susceptibility during the "Nile" growing season (July-October) is attributed to the rise in atmospheric humidity during this season.

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